TILBURG UNIVERSITY
KATHOLIEKE UNIVERSITEIT BRABANT
POSTBOX 90153
5000 LE TILBURG
THE NETHERLANDS

[redacted]

DEPARTMENT OF ECONOMICS

RESEARCH MEMORANDUM

THE EMPLOYMENT POLICY OF GOVERNMENT:
TO CREATE JOBS OR TO LET THEM CREATE?

Raymond H.J.M. Gradus

FEW 329

The employment policy of government: to create jobs or to let them create?

Raymond H.J.M. Gradus
Tilburg University, Postbox 90153 - 5000 LE Tilburg, The Netherlands

Abstract

In this paper we analyse the effect of corporate tax rate policy as an instrument to achieve more employment. A low level of corporate tax rate gives the firm more opportunities to invest and to create jobs, but on the other hand a high level of corporate tax rate increases the number of people working in the public sector. So there is a certain trade off between employment in the private sector and in the public sector. We apply a differential game framework to analyse this trade off and pay attention to different solution concepts (open-loop and feedback Stackelberg and Pareto). After comparing the results we can draw the conclusion that credibility and reputation play an important role in the effectivity of governmental employment policy.

1. Introduction

One of the important objectives of governmental policy nowadays is to lower the level of unemployment. Confronted with the high level of unemployment the government searches for instruments to achieve this goal. An important question in this respect is: should the government create jobs itself or should it let the firm create jobs. Assuming that governmental plans for employment will be financed by tax payments through the firm, the case of employment plans leaves less money for the firm to invest. Because of this lower level of investment there will be less growth of capital good stock and in the neo-classical framework less employment. So there is a certain trade off between employment created by the government and by the firm and the government's decision about the tax policy is affected by the investment policy of the firm.

In this paper we present a model for the firm, where the firm needs labour and capital for production and has to decide whether to invest its money after paying wages back into the firm or to pay out dividend. The firm has to reckon with the corporate tax policy of the government, which will be used as an instrument to achieve the governmental goal: employment. Because of the fact that the actions of one player will influence the outcome for the other , the class of differential game models seems to be a suitable framework for this problem. In a differential game different solution concepts and information structures (open-loop and feedback) are possible.

In section 2 we present the model for the case the firm operates under constant returns to scale. In section 3 the solutions for the different solution concepts and their economic interpretation are given. Special attention is paid to a comparison between open-loop Stackelberg, where the government commits itself to an announced policy at the beginning of the planning period, and feedback Stackelberg, where there is no commitment at all. In section 4 we discuss the case of decreasing returns to scale. In section 5 we give a numerical example for different parameter values of the production technique. Finally, in section 6 we make some remarks and suggestions for future research. In the appendix all technical details can be found.

2. The Model

As already mentioned in § 1 we will model the problem described in section 1 as a differential game:

[insert figure 1 here]

Assuming, that the firms can be represented by one, we have two players: the firm and the government.

2.1. The firm

We assume that the firm produces a homogeneous output by means of two homogeneous inputs: labor and capital goods. Its production function belongs to the class of Cobb-Douglas functions:

$$Q = K^{\delta} L^{1-\delta} \text{ , } 0 < \delta < 1 \text{ ,} \tag{1}$$

where Q: Production

K: capital good stock

L: labour

The relevant function is linearly homogeneous.
We assume that the amount of capital goods can only be raised by investment and there is no depreciation:

$$\overset{\circ}{K}(t) = I(t), \tag{2}$$

where I: investment.

We further assume that investment can only be financed by retained earnings. The firm brings this product on an output market, where it is faced with a fixed selling price p. Furthermore the firm has to pay the amount of labour a fixed wage rate w per unit.
This leads to the following expression for profit:

$$O(t) = pQ(t) - wL(t), \tag{3}$$

where O(t): profit

We assume that the firm behaves as if it maximizes the shareholders' value of the firm, which consists of the sum of the dividend streams over the planning period (see Lesourne (1978), Van Loon (1982)):

$$\max_{I,L} \int_{0}^{T} D(t)dt \text{ ,} \tag{4}$$

in which T : planning horizon

t : time

D(t): dividend

So the firm has to make two decisions: first it has to decide about its optimal amount of labour and second profit after taxation has to be divided between dividend and investment:

$$O(t) - TX(t) = I(t) + D(t), \tag{5}$$

in which: TX(t): tax payment

Because of the fact that L(t) does not appear in the system dynamically we can optimize the objective function statically with respect to L (see Feichtinger & Hartl (1986)). This leads to:

$$p.\frac{\partial Q}{\partial L} = w \tag{6}$$

Hence, at every time-point it holds that the marginal revenues of labour equals marginal costs of labour. In the case of a Cobb-Douglas technique (6) becomes:

$$L = \sqrt[\delta]{\frac{p(1-\delta)}{w}}.K \tag{7}$$

Thus, there is a linear relation between labour and capital and (3) can be rewritten as

$$\begin{aligned} O(t) &= (\frac{p}{\kappa} - w.\frac{\alpha}{\kappa})K(t) \qquad (8) \\ &= \{p.(\frac{p(1-\delta)}{w})^{\frac{1-\delta}{\delta}} - w.(\frac{p(1-\delta)}{w})^{\frac{1}{\delta}}\}K(t) \\ &= q.K(t), \end{aligned}$$

where κ: capital output coefficient

α: labour to output coefficient

q: rentability of capital good stock

In the case of constant returns to scale κ and α are constants.

2.2. The government

The government's objective is to maximize the employment during the planning period:

$$\max_{\tau} \int_0^T L^*(t)dt \tag{9}$$

The instrument for the government to achieve this goal is the corporate tax rate.
The amount of labour exists of two components:

$$L^*(t) = L(t) + L_G(t) \tag{10}$$

L : Labour working in the private sector

L_G: labour working in the public sector

L^* : total amount of labour

From section 2.1 it follows that the amount of employment in the private sector can be given by:

$$L(t) = \frac{\alpha}{\kappa} K(t) \tag{11}$$

We assume that the wage rates in the public and private sector are the same and the government will only use its money for paying wages. This leads to the following relation for employment in the public sector:

$$L_G(t) = \frac{G(t)}{w},$$

where $G(t)$: government spendings.

Furthermore, the government is not able to spend more than it receives (i.e. no budgetary deficit) and corporate tax is the only source of income for the government in this economy:

$$TX(t) = G(t) \tag{12}$$

$$TX(t) = \tau(t).O(t) \tag{13}$$

Finally, corporate tax rate is restricted between τ_1 and τ_2:

$$0 < \tau_1 \leqq \tau(t) \leqq \tau_2 < 1, \ \tau_1 \neq \tau_2 \tag{14}$$

In this model the government has to deal with the following interesting dilemma: it wants to maximize employment, so it may choose a high level of corporate tax rate, because in that case there is more money to create jobs. But on the other hand a high level of corporate tax rate implies that the firm has less money to invest, which yields less jobs created by the firm and less future jobs created by the government, because future tax earnings decrease.

3. The optimal solution

3.1. Introduction

Before we can derive an optimal solution we have to make some assumptions about the way that one player will react on an announcement of the other. Important is also the question whether the player commits itself to his announced policy or not. We will assume that the government takes into account the reaction of the firm to the announced tax rate. In section 3.2, where there is no commitment and the players do not cooperate, the outcome of the formal structure of the interaction between government and firm corresponds to a feedback Stackelberg dynamic game with the government as leader (e.g. Başar and Olsder (1982, sect. 7.3)). In section 3.3 we make the same behavioural assumptions, but now the government and firm commit theirselves to their announced policy. The outcome of the game corresponds to an open-loop Stackelberg solution (e.g. Başar and Olsder (1982, section 7.2)). In section 3.4 the Pareto case is treated. Here, government and firm cooperate and the absence or presence of binding contracts makes no difference.

3.2. The feedback Stackelberg solution

In the appendix we prove that the open-loop Nash solution is a candidate for a feedback Stackelberg equilibrium. This solution is not difficult to obtain and is presented in table 1 and table 2.

[insert table 1 and 2]

$$\bar{t} = T - \frac{\kappa}{(p-w\alpha)(1-\tau_2)} \tag{15}$$

$$\frac{d\bar{t}}{d\tau_2} < 0, \ \frac{d\bar{t}}{dp} > 0, \ \frac{d\bar{t}}{dw} < 0, \ \frac{d\bar{t}}{d\alpha} < 0, \ \frac{d\bar{t}}{d\kappa} > 0$$

$$\hat{t} = \bar{t} + \frac{\kappa}{(p-w\alpha)(1-\tau_2)} \ln \left\{\frac{p-(w-1)\alpha}{2(\alpha+\tau_2(p-w\alpha))}\right\} \tag{16}$$

In the beginning the government starts to tax at a low rate and the firm invests at its maximum rate. The reason for the government to ask the low rate is that more money is left for the firm to invest, which implies that future tax earnings and future employment will be greater. The firm invests at its maximum rate in order to be able to pay out more dividend in the future. At the moment $\bar{t}$ the firm stops investment and starts paying out dividend. Because the end of the planning horizon comes nearer the shareholders are more interested in collecting dividend than in investment.

In the feedback case the government will always ask the high rate after time-point $\bar{t}$, because the only incentive to ask the low rate is that the firm has more money to invest. The only question left is: will the government switch from high to low rate before or just at the moment that the firm changes its investment policy. If $\tau_2 < \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$, the government has already switched before the moment that the firm switches. Stated briefly, this situation occurs if the final tax rate is small, the labour to output coefficient is large, the profit per employee, i.e. p-wα, is large or there is a high level of wage rate.

In the case that $\tau_2 > \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$, stopping investment and raising the tax rate takes place at the same moment. Note that the government wants more investment (i.e. its shadowprice of capital is greater than one), but it cannot force the firm to invest.

3.3. The open-loop Stackelberg solution

In appendix 1 we used Pontryagin's maximum principle to derive the solution for this model. It turns out that is convenient to distinguish the following three situations:

1) $\tau_2 < \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$, open-loop is feedback (see table 2)

2) $\tau_1 < \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$; $\tau_2 > \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$: table 3

3) $\tau_1 > \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$: table 4

[insert table 3 and 4]

$$t_1 = T - \frac{w+1}{p}\kappa \tag{17}$$

$$\frac{dt_1}{dp} > 0,\ \frac{dt_1}{dw} < 0,\ \frac{dt_1}{d\kappa} > 0,\ \frac{dt_1}{d\alpha} = \frac{dt_1}{d\tau_1} = \frac{dt_1}{d\tau_2} = 0$$

$$t_2 = T - \frac{1-\tau_1(1+\frac{1}{w}) - \frac{\alpha}{p-w\alpha}}{(\tau_2-\tau_1)\cdot\frac{p}{w\kappa}} \tag{18}$$

$$\frac{dt_2}{dp} > 0,\ \frac{dt_2}{d\tau_1} < 0,\ \frac{dt_2}{d\tau_2} < 0,\ \frac{dt_2}{dw} < 0,\ \frac{dt_2}{d\alpha} < 0,\ \frac{dt_2}{d\kappa} < 0$$

$$t^1 = T - \frac{\kappa}{(p-w\alpha)(1-\tau_1)} \tag{19}$$

$$\frac{dt^1}{dp} > 0,\ \frac{dt^1}{d\tau_1} < 0,\ \frac{dt^1}{dw} < 0,\ \frac{dt^1}{d\alpha} < 0,\ \frac{dt^1}{d\kappa} < 0$$

Only in the case that $\tau_2 > \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$ there is a difference between the feedback and open-loop situation. It turns out that in the open-loop case there is more employment and more dividend pay-out. So the results of both players improve, if open-loop is played. In the open-loop case the firm's investment period becomes longer ($t_1 > \bar{t}$ or $t^1 > \bar{t}$) and there are more capital goods. The reason for this longer period of investment is that the government postpones the application of the high rate, because in this way investing becomes more attractive for the firm.

So to let create jobs is better than creating jobs. The main difference is that in the open-loop case a phase with zero investment and low tax rate is possible, while in the feedback case, because of the absence of commitment, there is no reason to believe that the government will ask the low rate if there is no investment. Hence, within the open-loop framework the government can influence the firm more to increase investment.

3.4. The cooperative outcomes

It can be shown that in general the outcomes of section 3.2 and 3.3 are inefficient, because there are combinations of investment policy and tax rate, which result in more employment and dividend pay-out. Pareto-efficient outcomes can be found from maximizing a weighted sum of both objective functions of firm and government:

$$\max_{I,L,\tau} \left[\int_0^T L^*(t)dt + \mu \int_0^T D(t)dt \right],\ 0 < \mu < \infty \tag{20}$$

subject to (1) - (3), (5) - (8) and (10) - (14), where μ can be interpreted as the bargaining power of the firm against the government.

We distinguish two possible situations, depending on the bargaining power of the firm against the government. If $\mu \leqq \frac{1}{w}$, the government is in a strong bargaining position, because for the 'social planner' one dollar more employment means more than one dollar dividend. In that case the solution consists of three phases.

[insert table 5]

The structure of this solution is the same as the feedback Stackelberg solution if $\tau_2 \leqq \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$. However, the reason for the fact that the investment switch takes place earlier than the tax switch is not the relatively low level of τ_2, but the strong bargaining position. If $\mu > \frac{1}{w}$, we have the opposite situation and the firm is in a strong bargaining position. In this case the government will stick to its low tax rate during the whole planning period.

[insert table 6]

However, not for every Pareto-efficient solution there will be higher employment as well as higher dividend than in the non-cooperative case. This will only happen for some values of μ (see figure 2).

[insert figure 2]

3.5. A further comparison between open-loop and feedback Stackelberg

At the moment, where the firm stops investing and starts paying out dividend, its valuation of a marginal increase in the capital good stock falls below unity. Hence, for its decision the firm will compare the extra stream of dividend in the future due to an extra dollar investment with collecting this dollar as dividend now, i.e. an increase of the objective function with one. The first term can be called present value of marginal investment and if this value is the largest the firm continues investing, otherwise the firm pays out dividend. Note that by calculating the marginal stream of dividend the firm will explicitly take into account the expected tax policy by the government. Also the government makes a comparison: it has the choice between leaving one dollar in the firm for investment or collecting this dollar as tax. If the government leaves this dollar in the firm, this has two effects. First the capital good stock will increase and because of that there is more employment in the private sector. Second, more capital goods will yield more tax earnings in the future, so the employment created by the government in the future increases. If the government collects this dollar, the amount of employees in the public sector increases with $\frac{1}{w}$. So the choice between the high or the low rate depends on the size of extra employment in the future due to a dollar investment. Is it less than $\frac{1}{w}$, then the government will ask the high rate, otherwise it will ask the low rate. With other words we can say that the choice of the tax policy depends on the effectivity of the employment policy.

We first look at the situation of the feedback information structure. If $\tau_2 < \frac{1-\frac{p}{p-w\alpha}}{1+\frac{1}{w}}$ at the moment $\hat{t}$ giving one dollar to the firm has an effect of $\frac{1}{w}$ to the employment level. After time-point $\hat{t}$, the government raises the tax rate, but the firm still continues investment. At the moment $\bar{t}$ the marginal earnings of marginal investment equals one and therefore the firm switches to the dividend-phase. If $\tau_2 > \frac{1-\frac{p}{p-w\alpha}}{1+\frac{1}{w}}$, the firm invests and the government asks the low rate until $\bar{t}$. At that time-point $\bar{t}$ the firm stops investment and the government raises tax. However, the valuation (in employment) of the government of a marginal increase in capital stock is still greater than $\frac{1}{w}$. The government wants more investment, because the extra employment due to one dollar investment is more than $\frac{1}{w}$. In spite of this it cannot force the firm to continue investing. And in the feedback case, at the moment that the firm stops investment, there is no incentive to ask the low rate.

In the situation of open-loop information structure the government will manipulate its tax policy in such a direction, that at the switching moment from investment to dividend, the marginal employment created by a marginal increase of investment by the firm equals $\frac{1}{w}$. In the case that

$\tau_2 < \dfrac{1-\frac{p}{p-w\alpha}}{1+\frac{1}{w}}$, there is no reason for manipulating, because during the firm's investment the valuation of the government already falls below $\frac{1}{w}$. In the case that $\tau_2 > \dfrac{1-\frac{p}{p-w\alpha}}{1+\frac{1}{w}}$ if the government announces a longer period of low tax, i.e. $t_2 > \bar{t}$, (compared to the feedback case) the firm goes on longer with investment, i.e. $t_1 > \bar{t}$. The reason for this is that both players will commit theirselves to their announced strategies. Therefore, the government continues asking the low rate, even if the firm has stopped investment. With other words the government chooses its optimal switch for the tax policy in such a direction, that its employment policy is optimal. Note that in the case where $\tau_1 > \dfrac{1-\frac{p}{p-w\alpha}}{1+\frac{1}{w}}$ even sticking to the low tax rate during the whole planning period is not enough to reach the point, where marginal employment created by the firm equals $\frac{1}{w}$.

However, for $\tau_2 > \dfrac{1-\frac{p}{p-w\alpha}}{1+\frac{1}{w}}$ the open-loop solution is time-inconsistent (e.g. Kydland and Prescott (1977)). This means that there exists a s, t such that $\tau^*(t,s) \neq \tau^*(t,0)$, where $\tau^*(t,s)$ is the optimal tax rate at time t if the government makes a new plan at time s. In our problem it is easy to understand that if the government has the possibility, at a moment between t_1 and t_2 (see table 3) to make a new initial plan, the high rate is the plan. In general the firm has no reason to believe that the government will stick to its initial plan, so open-loop Stackelberg is no longer a useful concept. In that case the feedback Stackelberg concept can be used. In spite of the fact that the outcome in employment and in dividend for the open-loop case is higher than for the feedback case. So for the government it is better to play open-loop, but this makes only sense if the firm believes the government. As pointed out in Gradus (1988) the credibility of governmental policy plays an important role in the effectivity of its instruments.

4. Decreasing returns to scale

In this section we will assume that the firm operates under decreasing returns to scale. Because we have fixed prices and wages, this decrease is caused by the fact that the production function is homogeneous of degree less than one. Furthermore, assume also now a Cobb-Douglas technology:

$$Q = K^{\delta}L^{\gamma};\ \delta + \gamma < 1;\ \delta,\ \gamma > 0 \tag{21}$$

An important implication of this assumption is that labour is no longer a linear function of capital good stock:

$$p\,\frac{\partial Q}{\partial L} = w \longrightarrow L = L(K) = \sqrt[1-\gamma]{\frac{p\gamma}{w}}.K^{\frac{\delta}{1-\gamma}} \tag{22}$$

$$L' > 0$$

$$L'' < 0$$

So if in this economy capital is increasing with, for example, 10% labour will increase with less than 10%.

[insert figure 3]

An other implication is that κ will not longer be a constant:

$$\alpha = \frac{p\gamma}{w} \tag{23}$$

$$\kappa(t) = (\frac{p\gamma}{w})^{\frac{1-\gamma}{\gamma}}.K(t)^{\frac{1-\gamma-\alpha}{1-\gamma}};\ \kappa' > 0,\ \kappa'' < 0 \tag{24}$$

So κ, i.e. the capital to output coefficient, increases in time and the economy becomes more and more capital-intensive (see also Van Loon (1982)). Hence, some substitution between labour and capital will take place, but this substitution is not enough to bring labour at a lower level. This situation could change if we introduce an imperfect output market (see Lesourne and Leban (1978)).

In what way will the solution in the case of decreasing returns to scale change in comparison with the solution in section 2? We focus our interest on the feedback and open-loop Stackelberg solution. In the feedback Stackelberg solution the situation of table 1 and 2 still holds. If $\tau_2 < \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$ we have table 1, otherwise table 2 will occur. However, the time-points where the switches take place, will change. The switch from investment to dividend can be given by:

$$\bar{t} = \frac{(1-\tau_2)\delta qT-K_0^{\frac{1-\gamma-\delta}{1-\gamma}}.(1-\gamma)}{q\{\tau_1-\tau_2)\delta+(1-\tau_1)(1-\gamma)\}} \tag{25}$$

$$\bar{t}_\gamma > 0,\ \bar{t}_\delta > 0,\ \bar{t}_{\frac{\delta}{1-\gamma}} > 0,$$

where q can be given by

$$q = \left[p.\left(\frac{p\gamma}{w}\right)^{\frac{\gamma}{1-\gamma}} - w.\left(\frac{p\gamma}{w}\right)^{\frac{1}{1-\gamma}}\right] \tag{26}$$

It is easy to check, that if $\gamma + \delta = 1$ then we have equation (15). Note that if $\delta/(1-\gamma)$, which we can interpret as a measure of decreasing returns to scale, approaches zero, $\bar{t}$ will also go to zero. In that case getting more capital yields no advantage with respect to labour or dividend. However, the introduction of decreasing returns to scale has implications on the effectivity of a low rate of corporate tax, but not on the dilemma of creating jobs by the government or to let create jobs by the firm.

In the case of open-loop Stackelberg not only the time-points where the different switches will take place change but also the boundaries, which tells us which type of solution takes place, change (see figure 4).

[insert figure 4 here]

In the case of decreasing returns to scale there is an incentive for the government to go on longer with asking the low rate. So, the importance of commitment will increase.

5. A numerical example

The nature of the solutions examined may be further clarified by a numerical example. The following parameter values are chosen:

$$p = 2,\ w = 1,\ K_0 = 1,\ T = 4,\ \tau_1 = 1/4,\ \tau_2 = 1/2.$$

We have calculated the objective functions for the firm and the government for the different solution concepts and taken into account four possible situations of the technical parameters (see table 7)

a) $\delta = 3/4,\ \gamma = 1/4$ (constant returns to scale, capital intensive)

b) $\delta = 1/2,\ \gamma = 1/2$ (constant returns to scale, labour intensive)

c) $\delta = 1/2,\ \gamma = 1/4$ (decreasing returns to scale, capital intensive)

d) $\delta = 3/8,\ \gamma = 1/4$ (decreasing returns to scale, labour intensive)

For the Pareto solution we distinguish two possible situations:

i) $u \uparrow \frac{1}{w}$, i.e. the government is in a strong bargaining position

ii) $u \downarrow \frac{1}{w}$, i.e. the firm is in a strong bargaining position.

[insert table 7 here]

In the first situation in the feedback case the firm stops investment at time-point 2.32. In the open-loop situation by announcing a longer period of low tax rate the firm continues investment until 2.80 and the government postpones the application of the high rate until 3.58. As already mentioned in section 3.3, the open-loop solution yields higher values of employment and dividend, but this is only credible if there are reasons to believe that the government will stick to its initial plan.

In the second situation, where capital goods are less profitable, there will be an earlier switch of investment in the Stackelberg game. However, there is more employment in this economy, because the firm creates more employment, i.e. $\alpha_1/\kappa_1 < \alpha_2/\kappa_2$. Because of that in the OLS-solution there is no switch of tax policy. Sticking to the low rate is better. In the case that $\tau_1 > \frac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$ the OLS solution belongs to the set of Pareto-efficient solution and equals the Pareto solution with extreme bargaining power for the firm.

This example also clarifies, that in the case of decreasing returns to scale the switch from investment to dividend will take place at a much earlier time-point than in the case of constant returns to scale; the intuition behind this is clear: capital goods are becoming less profitable. By decreasing returns to scale we have calculated the optimal solution for two different sets of parameter values, a capital intensive and a labour intensive situation. Although the rentability of the capital good stock is less in the second situation the switch will take place at a later moment of time. The reason lies in the fact that $\delta_1 + \gamma_1 = 3/4 < \delta_2 + \gamma_2 = 7/8$.

6. Conclusions

One of the important policy issues nowadays is to try to lower the level of unemployment. Confronted with a high level of unemployment the government searches for an instrument to achieve this goal. In this paper we focus our interest on the corporate tax rate as an instrument for the government to lower the level of unemployment. For the effects on employment, it is important to distinguish between employment in the private and in the public sector.

In this paper we present a theoretical model, where the government can create jobs and where the firms employ people. In this model, which gives a description of aspects of governmental employment policies, government and firms interact through investment and tax policy. The government can create more jobs in the public sector by raising the corporate tax rate, but on the other hand a high level of corporate tax rate lowers the capital good stock and under certain assumptions also the level of unemployment. So there is a certain trade off between employment in the public sector and employment in the private sector.

By assuming that the firms can be represented by one, we have a differential game with two players: government and firm. In this differential game we studied different solution concepts (feedback and open-loop Stackelberg and Pareto) and compared the results. An answer to the question: "what is better to create jobs or to let them create?" depends on the parameters of the model like α, i.e. the labour to output coefficient of the private sector. Special attention is paid to the difference between the open-loop Stackelberg, where both players sticks to their announced policy, and the feedback Stackelberg. In general the open-loop solution yields higher outcomes for both players, but it is only credible if there are reasons to believe that the government will stick to its announced policy. The main conclusion is that the credibility and reputation of governmental policy can have a great influence on the outcome of the model.

Of course, the analysis is in some sense partial. We did not analyse a labour and output market and assume wage rate and output price to be fixed. Also we can incorporate other tax and monetary instruments. These areas will be subjects for future research.

Acknowledgement

The author likes to thank Peter Kort, Piet Verheyen, Bertrand Melenberg, Aart de Zeeuw, Theo van de Klundert (Tilburg University), Paul van Loon, Onno van Hilten (University of Limburg) and Steffen Jørgensen (Odense University) for their valuable comments. Financial support by the Netherlands Organization for the Advancement of Pure Research is gratefully acknowledged.

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Appendix 1. The solution of the model presented in section two:

We can rewrite the model presented in section 2 as follows:

-objective function government:

$$\max_{\tau} \int_0^T (\frac{\alpha}{\kappa} + \tau(t)\frac{q}{w})K(t)dt, \ 0 \leq \tau_1 \leq \tau(t) \leq \tau_2 < 1 \tag{A1}$$

-objective function firm:

$$\max_{u} \int_0^T (q(1-\tau(t))(1-u(t))K(t)dt, \ 0 \leq u(t) \leq 1, \tag{A2}$$

where $u(t) := I(t)/(O(t)-TX(t))$

-state equation:

$$\dot{K}(t) = q(1-\tau(t))u(t)K(t), \tag{A3}$$

where q is given by (8).

As mentioned in section 2 the optimal level of employment by the firm is a linear function of the capital good stock:

$$L(t) = \frac{\alpha}{\kappa}K(t) \tag{A4}$$

1.1. The feedback Stackelberg solution

The necessary conditions for a feedback Stackelberg solution are (see Başar and Haurie (1985)):

there exists value functions $V_1(t,K)$ and $V_2(t,K)$ such that:

$$-\frac{\partial V_1(t,K)}{\partial t} = \max_{\tau \in [\tau_1,\tau_2]} \{(\frac{\alpha}{\kappa} + \tau\frac{q}{w})K(t) + \frac{\partial V_1}{\partial K}q(1-\tau)\psi_2(t,K)K\} \tag{A5}$$

$$-\frac{\partial V_2(t,K)}{\partial t} = \max_{u \in [0,1]} \{q(1-\psi_1(t,K,u))(1-u)K(t) + \frac{\partial V_2}{\partial K}q(1-\psi_1(t,K,u))uK\} \tag{A6}$$

$$V_1(T,K(T)) = 0 \tag{A7}$$

$$V_2(T,K(T)) = 0 \tag{A8}$$

$$(\frac{\alpha}{\kappa} + \psi_1(t,K,u)\frac{q}{w})K + \frac{\partial V_1}{\partial K}q(1-\psi_1(t,K,u))uK \geq (\frac{\alpha}{\kappa} + \tau\frac{q}{w})K + \frac{\partial V_1}{\partial K}q(1-\tau)uK,$$
$$\forall \tau \in [\tau_1,\tau_2], \ \forall u \in [0,1], \tag{A9}$$

where ψ_1 and ψ_2 are mappings such that

$$\psi_1:(t,K,u) \to \tau(t) \in [\tau_1,\tau_2] \tag{A10}$$

$$\psi_2:(t,K) \to u(t) \in [0,1] \tag{A11}$$

It would be straightforward to check that the following linear value function is a solution of (A5)-(A11):

$$V_i(t,K) = \lambda_i(t).K\ , \tag{A12}$$

where λ_1 and λ_2 are given by:

$$\dot{\lambda}_1 = -\frac{\alpha}{\kappa} - \tau\frac{g}{w} - \lambda_1 u(1-\tau)q,\ \lambda_1(T)=0 \tag{A13}$$

$$\dot{\lambda}_2 = -q(1-\tau)(1-u) - \lambda_1 u(1-\tau)q,\ \lambda_2(T)=0 \tag{A14}$$

From (A4), (A5) and (A11) follows that

$$\gamma_1(t,K,u) = \tau_2 \quad \text{if} \quad 1-\lambda_1 u > 0 \tag{A15}$$

$$\gamma_1(t,K,u) = \tau_1 \quad \text{if} \quad 1-\lambda_1 u \leq 0 \tag{A16}$$

$$\gamma_2(t,K) = 1 \quad \text{if} \quad \lambda_2 \geq 1 \tag{A17}$$

$$\gamma_2(t,K) = 0 \quad \text{if} \quad \lambda_2 < 1 \tag{A18}$$

So the open-loop Nash is a candidate for the feedback Stackelberg solution, because λ_1 and λ_2 are the same functions as the costate functions of the open-loop Nash solution.

1.2. The open-loop Stackelberg solution

The necessary conditions for an open-loop Stackelberg solution $(\hat{\tau},\ \hat{u})$ are (Wishart and Olsder (1979)):

$$H_1(\hat{K},\ \hat{\tau},\ \hat{u},\ \lambda_1,\ \pi) \geq H_1(\hat{K},\ \tau,\ \hat{u},\ \lambda_1,\ \pi),\ \forall\ \tau \in [\tau_1,\tau_2] \tag{A19}$$

$$H_2(\hat{K},\ \hat{\tau},\ \hat{u},\ \lambda_2) \geq H_2(\hat{K},\ \hat{\tau},\ u,\ \lambda_2),\ \forall\ u \in [0,1] \tag{A20}$$

$$\dot{\lambda}_1 = -\frac{\alpha}{\kappa} - \hat{\tau}\frac{g}{w} - \lambda_1 \hat{u}(1-\hat{\tau})q,\ \lambda_1(T)=0 \tag{A21}$$

$$\dot{\lambda}_2 = -q(1-\hat{\tau})(1-\hat{u}) - \lambda_2 \hat{u}(1-\hat{\tau})q,\ \lambda_2(T)=0 \tag{A22}$$

$$\dot{\pi} = -q(1-\hat{\tau})\hat{u}\pi - q(1-\hat{\tau})\{\lambda_1 K+(1-\lambda_2)\pi\}\frac{d\hat{u}}{d\lambda_2} \tag{A23}$$

$$\pi(0) = 0, \tag{A24}$$

where H_1 and H_2, the Hamiltonians are defined by

$$H_1 = (\frac{\alpha}{\kappa} + \tau\frac{q}{w})K + \lambda_1 q(1-\tau)uK - \pi\{q(1-\tau)(1-u)+\lambda_2 u(1-\tau)q\} \tag{A25}$$

$$H_2 = qK(1-\tau)(1-u) + \lambda_2 qK(1-\tau)u \tag{A26}$$

For the government's optimal tax rate we can derive

$$\tau(t) = \begin{cases} \tau_1 & \text{if } B(t) < 0 \\ & \\ \tau_2 & \text{if } B(t) > 0 \end{cases}, \tag{A27}$$

$$\text{where } B(t) = (\frac{1}{w}-\lambda_1 u)K + \pi\{(1-u)+\lambda_2 u\} \tag{A28}$$

Applying the results of Wishart and Olsder (1979) we can evaluate the costate variable $\pi(t)$. The term $\frac{d\hat{u}}{d\lambda_2}$ behaves with respect to time as a δ-function with a jump at $t = t_1$. The size of this jump is determined by the properties of the δ-function (see Wishart and Olsder (1979)). So $\pi(t)$ will be zero until the moment that the firm switches from investment to dividend and will have a jump at $t = t_1$:

$$\pi(t_1) = -\lambda_1(t_1)K(t_1) \tag{A29}$$

so that

$$B(t_1) = (\frac{1}{w} - \lambda_1(t_1))K(t_1) \gtrless 0 \text{ if } \lambda_1(t_1) \lessgtr \frac{1}{w} \tag{A30}$$

It depends on the value of $\lambda_1(t_1)$, which policy will be chosen. We have three possible situations:

-1) $\lambda_1(t_1) < \frac{1}{w} \Rightarrow \tau(t) = \tau_2,\ t \geq t_1$ (A30)

This will happen if $\tau_2 < \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$

From the transversality condition t_1 can be derived, which is the same as in the feedback situation.

-2) $\lambda_1(t_1) > \frac{1}{w} \Rightarrow \tau(t) = \tau_1,\ t \geq t_1$ (A31)

This will happen if $\tau_1 > \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$.

In the text we replace t_1 by t^1 to clearify the difference between situation two and three.

-3) $\lambda_1(t_1) = \frac{1}{w} \Rightarrow \tau(t) = \tau_1,\ t_1 \leq t < t_2$

$$= \tau_2,\ t_2 \leq t \leq T \tag{A32}$$

This situation will occur if $\tau_1 < \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$ and $\tau_2 > \dfrac{1-\frac{\alpha}{p-w\alpha}}{1+\frac{1}{w}}$

The time-points t_1 and t_2 can be derived from the system $\lambda_1(t_1)=\frac{1}{w}$ and $\lambda_2(t_1)=1$, which contains two unknown variables and two equations (see also Gradus (1988)).

The conditions for the open-loop Stackelberg solution are not only necessary but also sufficient because of the fact that the maximized Hamiltonians are linear with respect to the state variable.

1.3. The Pareto solution

To find the Pareto-solution we have to maximize $J = J_1 + \mu J_2,\ 0 < \mu < \infty$ subject to (A3), where μ measures the relative importance of player 1 against player 2 and is assumed to be given. This is a standard optimal control problem, which is easy to solve. We give no details about the derivation. The time-points in table 6 and 7 can be given by:

$$t' = \frac{\mu\kappa w}{w\alpha + \tau_1(p-w\alpha) + \mu w(p-w\alpha)(1-\tau_1)} \tag{A33}$$

$$\tilde{t} = \frac{\mu\kappa w}{w\alpha + \tau_2(p-w\alpha) + \mu w(p-w\alpha)(1-\tau_2)} \tag{A34}$$

$$\tilde{\tilde{t}} = \tilde{t} - \frac{1}{q(1-\tau_2)}\ ln\ \{(\mu+\frac{w\alpha+\tau_2(p-w\alpha)}{w(1-\tau_2)(p-w\alpha)})/(\frac{1}{w}+\frac{w\alpha+\tau_2(p-w\alpha)}{w(1-\tau_2)(p-w\alpha)})\} \tag{A35}$$

Appendix 2. the solution of the model presented in section 4

We have only derived the feedback and open-loop Stackelberg solution.

2.1. The feedback solution

Again the open-loop Nash solution is a candidate for the feedback Stackelberg solution. The solution (u_1^*, u_2^*) for the OLN-problem is easy to derive. The necessary conditions are:

$$H_1(K, \tau^*, u^*, \lambda_1) \geq H_1(K, \tau, u^*, \lambda_1), \ \forall \tau \in [\tau_1, \tau_2] \tag{A36}$$

$$H_2(K, \tau^*, u^*, \lambda_2) \geq H_2(K, \tau^*, u, \lambda_2), \ \forall u \in [0,1] \tag{A37}$$

$$\dot{\lambda}_1 = -(\frac{\alpha}{\kappa} + \frac{\tau^*}{w})\frac{dO}{dK} - \lambda_1 u^*(1-\tau^*)\frac{dO}{dK}, \ \lambda_1(T)=0 \tag{A38}$$

$$\dot{\lambda}_2 = -(1-\tau^*)(1-u^*)\frac{dO}{dK} - \lambda_1 u^*(1-\tau^*)\frac{dO}{dK}, \ \lambda_2(T)=0, \tag{A39}$$

where H_1 and H_2, the Hamiltonians are defined by

$$H_1 = (\frac{\alpha}{\kappa} + \frac{\tau}{w})O(K) + \lambda_1(1-\tau)uO(K) \tag{A40}$$

$$H_2 = (1-\tau)(1-u)O(K) + \lambda_2(1-\tau)uO(K) \tag{A41}$$

$O(K) = qK^{\frac{\gamma}{1-\delta}}$, where q is given by (26)

2.2. The open-loop Stackelberg solution

The necessary conditions for the open-loop Stackelberg solution $(\bar{\tau}, \bar{u})$ in the case of decreasing returns to scale:

$$H_1(K, \bar{\tau}, \bar{u}, \lambda_1, \pi) \geq H_1(K, \tau, \bar{u}, \lambda_1, \pi), \ \forall \tau \in [\tau_1, \tau_2] \tag{A42}$$

$$H_2(K, \bar{\tau}, \bar{u}, \lambda_2) \geq H_2(K, \bar{\tau}, u, \lambda_2), \ \forall u \in [0,1] \tag{A43}$$

$$\dot{\lambda}_1 = -(\frac{\alpha}{\kappa} + \frac{\bar{\tau}}{w})\frac{dO}{dK} - \lambda_1\bar{u}(1-\bar{\tau})\frac{dO}{dK} - \pi\frac{d^2O}{dK^2}(1-\bar{\tau})(1-\bar{u}), \ \lambda_1(T)=0 \tag{A44}$$

$$\dot{\lambda}_2 = -\frac{dO}{dK}(1-\bar{\tau})(1-\bar{u}) - \lambda_2\bar{u}(1-\bar{\tau})\frac{dO}{dK}, \ \lambda_2(T)=0 \tag{A45}$$

$$\dot{\pi} = -\frac{dO}{dK}(1-\bar{\tau})\bar{u}\pi - (1-\bar{\tau})\{\lambda_1 O(K) + (1-\lambda_2)\pi\frac{dO}{dK}\}\frac{d\bar{u}}{d\lambda_2} \tag{A46}$$

$$\pi(0) = 0, \tag{A47}$$

where H_1 and H_2, the Hamiltonians are defined by

$$H_1 = \left(\frac{\alpha}{\kappa} + \frac{\tau}{w}\right)O(K) + \lambda_1(1-\tau)uO(K) - \pi\frac{dO}{dK}(1-u+\lambda_2 u)(1-\tau) \tag{A48}$$

$$H_2 = (1-\tau)(1-u)O(K) + \lambda_2(1-\tau)uO(K) \tag{A49}$$

In the same way as in 1.2. we can evaluate the costate variable $\pi(t)$. The time-points t_1 and t_2 are

$$T - t_2 = \frac{g(1-\tau_1) - \frac{g}{w}(\tau_1 + \frac{\gamma}{1-\gamma}) - h(1-\tau_1)}{g(\tau_2-\tau_1)(\frac{g}{w}(\frac{\gamma}{1-\gamma} + 1))} \tag{A50}$$

$$T - t_1 = \frac{g + \frac{g}{w} + h}{g\frac{g}{w}(\frac{\gamma}{1-\gamma} + 1)}, \tag{A51}$$

where $g = \frac{dO}{dK}$ and $h = \frac{d^2O}{dK^2}$

Figure and table captions

Table 1. The FBS solution (if $\tau_2 \geq \dfrac{1 - \dfrac{\alpha}{p-w\alpha}}{1 + \dfrac{1}{w}}$)

Table 2. The FBS solution (if $\tau_2 < \dfrac{1 - \dfrac{\alpha}{p-w\alpha}}{1 + \dfrac{1}{w}}$)

Table 3. The OLS solution (if $\tau_1 \leq \dfrac{1 - \dfrac{\alpha}{p-w\alpha}}{1 + \dfrac{1}{w}}$ and $\tau_2 \geq \dfrac{1 - \dfrac{\alpha}{p-w\alpha}}{1 + \dfrac{1}{w}}$)

Table 4. The OLS solution (if $\tau_1 > \dfrac{1 - \dfrac{\alpha}{p-w\alpha}}{1 + \dfrac{1}{w}}$)

Table 5. The Pareto-solution (if $0 < \mu < \frac{1}{w}$)

Table 6. The Pareto-solution (if $\mu > \frac{1}{w}$)

Table 7. A numerical example

Figure 2. The optimal trajectories of capital and labour

Figure 3. The value of the objective functions by different solution concepts

Figure 4. The τ-values for the different solutions

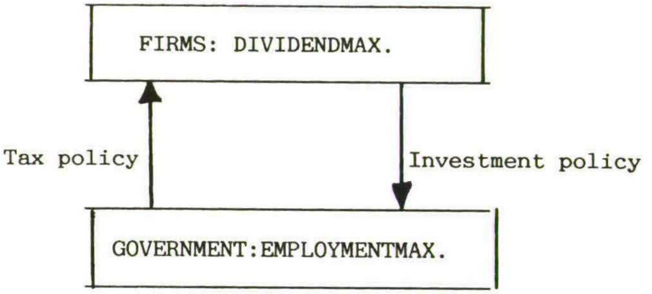


FIGURE 1

	$t \in [0,\bar{t})$	$t \in [\bar{t},T]$
$\tau(t)$	τ_1	τ_2
$u(t)$	1	0

TABLE 1

	$t \in [0,\hat{t})$	$t \in [\hat{t},\bar{t})$	$t \in [\bar{t},T]$
$\tau(t)$	τ_1	τ_2	τ_2
$u(t)$	1	1	0

TABLE 2

	$t \in [0,t_1)$	$t \in [t_1,t_2)$	$t \in [t_2,T]$
$\tau(t)$	τ_1	τ_1	τ_2
$u(t)$	1	0	0

TABLE 3

	$t \in [0,t^1)$	$t \in [t^1,T]$
$\tau(t)$	τ_1	τ_1
$u(t)$	1	0

TABLE 4

	$t \in [0,\tilde{\tilde{t}})$	$t \in [\tilde{\tilde{t}},\tilde{t})$	$t \in [\tilde{t},T]$
$\tau(t)$	τ_1	τ_2	τ_2
$u(t)$	1	1	0

TABLE 5

	$t \in [0,t')$	$t \in [t',T]$
$\tau(t)$	τ_1	τ_1
$u(t)$	1	0

TABLE 6

			FBS			OLS				Pareto		
	α	κ	J_1	J_2	$\bar{t}$	J_1	J_2	t_1	t_2	J_1	J_2	t^*
$\gamma=3/4,\ \delta=1/4$	0.5	1.3	18.6	7.9	2.3	19.7	11.5	2.7	3.6	27.7	10.2	3.4
										23.9	15.2	
$\gamma=1/2,\ \delta=1/2$	1.0	1.0	19.2	4.5	2.0	23.0	7.4	2.7	4	31.7	3.5	3.5
										30.0	5.2	
$\gamma=1/2,\ \delta=1/4$	0.5	1.3	6.0	2.9	0.9	6.2	3.3	1.0	1.3	9.3	2.8	2.4
										7.9	4.2	
$\gamma=3/8,\ \delta=1/2$	1.0	1.0	9.3	2.5	0.9	10.9	3.9	1.7	4.0	16.7	2.0	3.0
										15.7	2.9	

TABLE 7

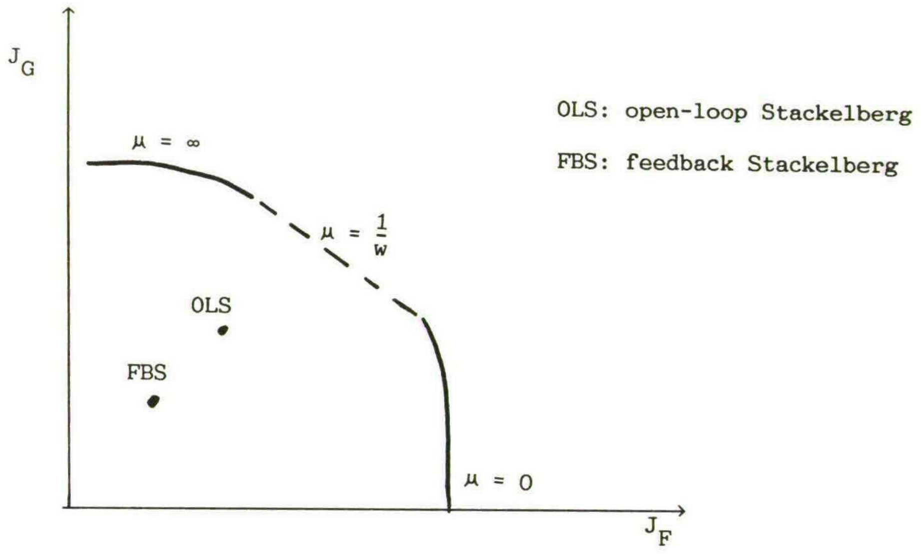

J_G
OLS: open-loop Stackelberg
FBS: feedback Stackelberg
$\mu = \infty$
$\mu = \frac{1}{w}$
OLS
FBS
$\mu = 0$
J_F

Figure 2.

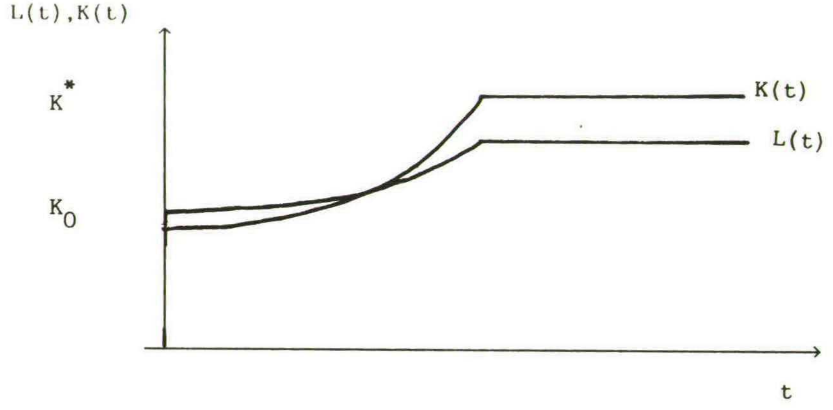
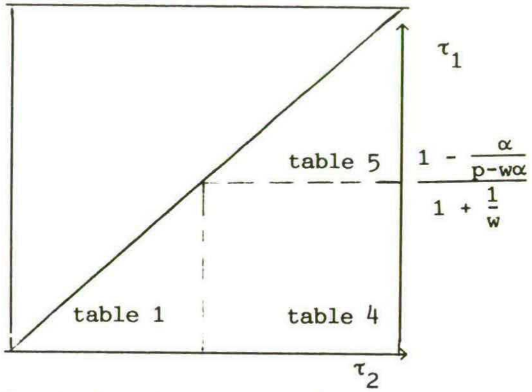
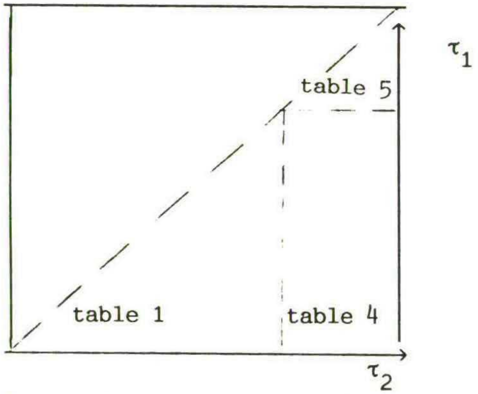


Figure 3.



Constant returns to scale



Decreasing returns to scale

Figure 4.

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