The Effects of Subsidies in a Research-Driven Endogenous Growth Model

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Abstract

This paper focuses on the allocation and growth effects of different types of subsidies aimed at rectifying the two distortions that occur in research-driven growth models of the Romer (1990) type. These distortions lead to a suboptimal growth rate and are caused by the monopolistic structure of the capital goods market and the public good character of knowledge which is created as a by-product of R&D and induces positive intertemporal externalities. We show that the effects depend heavily on the design of the subsidies, implying different policy mix possibilities to achieve the optimal output level and growth rate.

1. Introduction

In his seminal paper Romer (1990) develops an endogenous growth model, in which output growth is driven by a private, profit-seeking research and development sector (R&D). An important implication of this model is that, due to the monopolistic structure of the capital goods market and the public good character of knowledge which is created as a by-product of R&D, the economy is distorted in two ways leading to a suboptimal growth rate. The purpose of this paper is to examine whether the usual argument, that distortions can be rectified by subsidies, also applies in an endogenous growth approach. Specifically, we examine the allocation and growth effects of different types of subsidies to R&D enterprises and capital goods producers. Furthermore, it is shown that design for an optimal subsidy policy is set forth. The analysis shows that the effects of a subsidy depend crucially on how the subsidy is designed. This makes it necessary to decide between different policy mixes in order to achieve optimal results. The rest of the paper is structured as follows. Section 2 briefly sketches the model. Sections 3 and 4 study the effects of different subsidies to R&D enterprises and capital goods producers, respectively. Section 5 examines the optimal policy mix of subsidies and section 6 presents the summary and conclusions.

2. The formal framework

Our analysis uses the basic structure of the Romer (1990) model. We refer the reader to that paper for a complete exposition. Production comprises two sectors, a manufacturing sector producing consumption and capital goods and an R&D sector producing designs for innovative capital goods. The production function of the R&D sector is

$$\dot{A} = \delta H_A A , \qquad (1)$$

whereA is the amount of new blueprints and δ is a productivity parameter. The variable A denotes the total stock of blueprints invented in the past and is also used as a proxy for the knowledge stock, which affects R&D productivity. Thus, new designs add to the knowledge and, thereby, increase future R&D productivity. H_A is human capital employed in R&D. The production function of manufacturers is

$$Y = H_Y^{\alpha} L^{\beta} \int_0^A x(i)^{\gamma} di = H_Y^{\alpha} L^{\beta} A x^{\gamma} \qquad with\ \alpha + \beta + \gamma = 1 . \tag{2}$$

Here, Y, L, H_Y, and x are output, unskilled labor, human capital in manufacturing, and symmetrical capital goods, respectively. This production function applies to both consumption and capital goods. The endowment with human capital (H) and labor (L) is fixed. Intersectoral mobility of human capital and wage flexibility ensures full employment, implying that $H=H_A+H_Y$. Gross domestic product (GDP) of the economy is the sum of the value added created in the R&D sector and the value added created in the manufacturing sector. The value of a design in units of consumption goods is given by the relative price of a design (P_A). Therefore, gross domestic product in units of consumption goods is given by

$$GDP = H_Y^{\alpha} L^{\beta} A^{\alpha+\beta} \kappa^{\gamma} + P_A \delta A H_A , \tag{3}$$

where κ is defined as the sum of all capital goods produced (κ=Ax).

Capital goods can only be produced if the manufacturer possesses a patent for a distinct design developed by an R&D enterprise. Through the purchase of the patent the manufacturer incurs fixed costs but, at the same time, becomes a monopolist for one distinct type of capital goods. This enables him to reap a monopoly rent which can be used to pay for the design. The monopolist rents out the capital goods to other manufacturers. His marginal costs can be expressed in terms of foregone consumption goods, which is the interest rate (r). The other manufacturers are willing to pay a price (p_0) for a representative distinct capital good (x_0), expressed in units of consumption goods, equal to the marginal product of one unit of a representative capital good, which is

$$p_0 \;=\; \frac{\partial Y}{\partial x_0} \;=\; \gamma\, H_Y^{\alpha}\, L^{\beta}\, x_0^{\gamma\text{-}1} \;. \tag{4}$$

This shows that the demand for capital goods is isoelastic with elasticity $-1/(1-\gamma)$. Henceforth, we omit the suffix, since capital goods are assumed to be symmetrical. According to Chamberlinian markup pricing it is optimal for a monopolist to charge a constant markup over marginal costs, which implies $p=r/\gamma$. Thus, the monopoly rent is $\pi=(1-\gamma)xr/\gamma$.

The price of a design (P_A) is determined in a polypolistic market. In equilibrium, the discounted sum of all monopoly rents of a capital goods producer (π/r) equals the marginal costs of inventing a design

$$P_A \;=\; \frac{1\text{-}\gamma}{\gamma}\, x \;=\; \frac{w_{HA}}{\delta A}\;, \tag{5}$$

where w_{HA} is the wage rate for human capital employed in R&D. The wage rate of human capital in manufacturing (w_{HY}) can be derived by differentiating equation (2) with respect to H_Y, replacing L^{β} from equation (4), and using the fact that $p=r/\gamma$. Supply side equilibrium requires wage rate equalization:

$$w_{HY} \;=\; \frac{\alpha}{\gamma^2}\frac{Ax}{H_Y}\, r \;=\; \frac{1\text{-}\gamma}{\gamma}\,\delta A x \;=\; w_{HA}\;. \tag{6}$$

Demand side equilibrium is determined by the Keynes-Ramsey rule, given by

$$g \;=\; \frac{\dot{C}}{C} \;=\; \frac{r\text{ - }\rho}{\sigma}\;. \tag{7}$$

The representative agent exhibits a constant intertemporal elasticity of substitution ($1/\sigma$) and a constant rate of time preference (ρ). Combining demand and supply side conditions Romer yields the balanced growth rate as

$$g = \frac{\delta H - \rho\psi}{1+\sigma\psi} \, , \qquad \text{with } \psi = \frac{\alpha}{\gamma(1-\gamma)} \, . \tag{8}$$

The market economy suffers from two distortions. First, the monopolistic market structure drives a wedge between the marginal product and the marginal costs of capital goods. As a result, the supply of capital goods is too low. In an undistorted economy the interest rate (marginal costs of producing a capital good) would equal the annual capital goods price (the marginal product of a representative capital good (x_0)),

$$p_0 = r = \frac{\partial Y}{\partial x_0} = \gamma H_Y^{\alpha} L^{\beta} x_0^{\gamma-1} \, . \tag{9}$$

This would lead to an optimal supply of capital goods.

Second, R&D activities increase the knowledge stock of the economy and, thereby, the productivity of future R&D efforts. Since, knowledge is assumed to be a public good, no compensation is provided for this intertemporal spillover effect. In an optimum, however, the price of a design would equal all the returns induced by a new design, i.e., the discounted sum of all increases in gross domestic product (GDP). Thus, the value of a new design is

$$P_A = \int_s^{\infty} e^{-r(t-s)} \frac{\partial GDP}{\partial A} dt = \frac{(\alpha+\beta) H_Y^{\alpha} L^{\beta} A^{-\gamma} \kappa^{\gamma} + P_A \delta H_A}{r} \, . \tag{10}$$

Solving the equation above for P_A, using equation (7), the fact that $\alpha+\beta=1-\gamma$, and $g=\delta H_A$, this leads to the optimal price of a design, given by

$$P_A = \frac{1-\gamma}{\gamma} x \frac{r}{r-g} \, . \tag{11}$$

Both distortions reduce the profitability of the R&D sector and lead to a suboptimal growth rate.

This can be shown by deriving the optimal growth rate. Intersectoral equilibrium requires that the wage rates for human capital in an undistorted economy are equalized. Thus, the equilibrium wage rate (w) is

$$\tilde{w}_{HY} \;=\; \frac{\alpha}{\gamma}\frac{Ax}{H_Y}r \;=\; \frac{1-\gamma}{\gamma}\delta Ax\frac{r}{r-g} \;=\; \tilde{w}_{HA} \;. \tag{12}$$

Combining this equation with the Keynes-Ramsey rule (equation (7)) yields the optimal growth rate (g)

$$\tilde{g} \;=\; \frac{\delta H - \rho\psi\gamma}{(1-\psi\gamma)+\sigma\psi\gamma} \;. \tag{13}$$

The optimal growth rate (equation (13)) is higher than the growth rate of the market economy (equation (8)). An adequate policy would be to subsidize the R&D sector and the capital goods sector as well. The implications of such policies are discussed below.

3. The effects of R&D subsidies

Throughout the paper, we consider ad valorem subsidies, which are financed by lump-sum taxes. We begin the analysis by examining a revenue-enhancing subsidy (z_R^A) to R&D enterprises aimed at compensating the R&D sector for creating positive intertemporal externalities. The revenue of inventing a new design is $(1+z_R^A)P_A$. Hence, the wage rate paid for human capital in the R&D sector increases. The new intersectoral equilibrium is given by

$$w_{HY} \;=\; \frac{\alpha}{\gamma^2}\frac{Ax}{H_Y}r \;=\; (1+z_R^A)\frac{1-\gamma}{\gamma}\delta Ax \;=\; w_{HA} \;. \tag{14}$$

Since the wage rate for human capital in the manufacturing sector is not directly affected by the subsidy, human capital is shifted from the manufacturing sector to the R&D sector, which increases the growth rate to

$$g = \frac{(1+z_R^A)\delta H - \rho\psi}{1+z_R^A+\sigma\psi} \ . \tag{15}$$

Alternatively, a subsidy granted as a percentage of R&D marginal costs (z_C^A) would lead to a price of a design, given by $P_A=(1-z_C^A)w_{HA}/(\delta A)$. Thus, the intersectoral equilibrium condition becomes

$$w_{HY} = \frac{\alpha}{\gamma^2}\frac{Ax}{H_Y}r = \frac{1}{1-z_C^A}\frac{1-\gamma}{\gamma}\delta Ax = w_{HA} \ . \tag{16}$$

Note that a revenue enhancing R&D subsidy $1+z_R^A$ triggers exactly the same effects as a cost reducing subsidy $1/(1-z_C^A)$. An optimal R&D subsidy raises the price of the designs to a level, which incorporates the social returns from the intertemporal spillover effect. Thus, the subsidy rate that internalizes the intertemporal externality of R&D activities is either $1+z_R^A=r/(r-g)$ or $1-z_C^A=(r-g)/r$ (compare equations (5) and (11)). Using this in equation (14) or (16) and combining this with equation (7) leads to the modified growth rate

$$g = \frac{\delta H - \rho\psi}{(1-\psi)+\sigma\psi} \ . \tag{17}$$

It can easily be seen that an R&D subsidy leads to a growth rate which is smaller than the optimal growth rate shown in equation (13). The reason is that the optimal growth rate results only if both distortions occuring in the model are eliminated. However, the optimal growth rate could be reached by subsidizing the R&D sector more heavily. But even then the distortion in the capital goods sector would still remain leading to a suboptimal supply of capital goods, and therefore, to a suboptimal level of GDP.[1]

4. Subsidies to capital goods producers

In contrast to the analysis above, the effects of a subsidy to monopolistic capital goods producers aimed at eliminating the price distortion caused by the monopolistic market structure are heavily dependend on whether the subsidy enhances revenues or reduces marginal costs. We first consider a revenue-enhancing subsidy (z_R^M). The monopoly rent of a representative capital goods producer becomes

$$\pi = (1 + z_R^M)px - rx . \tag{18}$$

Maximizing these rents leads to a capital goods price $p=r/((1+z_R^M)\gamma)$. The lower price of capital goods leads to a substitution of capital goods for human capital in manufacturing. As a result, human capital shifts from the manufacturing sector into the R&D sector. Since the capital goods production rises and the interest rate increases to

$$r = (1 + z_R^M)\gamma^2 H_Y^\alpha L^\beta x^{\gamma-1} , \tag{19}$$

the monopoly rent also increases and becomes

$$\pi = \frac{1-\gamma}{\gamma} xr . \tag{20}$$

The new intersectoral equilibrium condition is

[1] This is the case because the growth rate in equation (15) increases with the subsidy rate z_R^A, so that even the maximum growth rate (δH) can be reached by an appropriate subsidy policy. Note, that the maximum growth rate is reached when the revenue-enhancing subsidy rate (z_R^A) becomes infinity or when the costs reducing subsidy rate (z_C^A) becomes one.

$$w_{HY} \;=\; \frac{1}{1+z_R^M}\frac{\alpha}{\gamma^2}\frac{Ax}{H_Y}r \;=\; \frac{1-\gamma}{\gamma}\delta Ax \;=\; w_{HA} \;. \tag{21}$$

Comparing equations (14) and (21) shows that a revenue-enhancing subsidy leads to the same allocation effect, independent of whether it is granted to R&D enterprises or capital goods producers. In both cases the new growth rate can be expressed by equation (15) if the variable z_R^A is replaced by z_R^M.

At first glance, this seems to be a surprising result. The different types of subsidies assigned to eliminate different distortions affect the relative wage for human capital in exactly the same way, and thus lead to the same growth effects. The reason for this is that the intersectoral equilibrium condition links the market for designs (equation (5)) and the condition for the optimal input ratio in manufacturing (left hand side of equation (6)). The optimal growth rate can be reached by choosing either an R&D subsidy $1+z_R^A=r/((r-g)\gamma)$ or a subsidy to the capital goods producers $1+z_R^M=r/((r-g)\gamma)$. However, the level effects would be different. In the first case, the wedge between the marginal product of capital goods and the marginal costs would not vanish. As a result, the demand for capital goods would be lower than in the optimum, and thus, both the capital stock and output would be lower too. In the second case the demand for capital goods would be too high, so that the capital stock, and thus, investment would be too high. As a result, consumption possibilities would be lost.

A subsidy rate aimed at completely eliminating the factor price distortion resulting from the monopolistic structure of the capital goods market equalizes the interest rate to the marginal product of the capital goods (p). This can be achieved by choosing a subsidy rate according to $1+z_R=1/\gamma$. The growth rate then becomes

$$g \;=\; \frac{\delta H - \rho\psi\gamma}{1+\sigma\psi\gamma} \;. \tag{22}$$

This growth rate is higher than the market growth rate (equation (8)) and smaller than the optimal growth rate (equation (13)).

We now show that the outcome is different when a subsidy (z_C^M) is granted to capital goods producers as a percentage of marginal costs. In this case, the monopoly rent is given by

$$\pi = px - (1 - z_C^M) rx . \tag{23}$$

Maximizing the monopoly rent leads to a price ($p=(1-z_C^M)r/\gamma$) of capital goods. The interest rate can be derived as

$$r = \frac{1}{1 - z_C^M} \gamma^2 H_Y^\alpha L^\beta x^{\gamma-1} \tag{24}$$

and the monopoly rent becomes

$$\pi = (1 - z_C^M) \frac{1-\gamma}{\gamma} xr . \tag{25}$$

Note that the elasticity of demand for capital goods is relatively high, i.e. $1/(1-\gamma)>1$. Therefore, a decline in the price for capital goods by the factor $(1-z_C^M)$ increases the demand for capital goods by more than this factor. A subsidy eliminating the factor price distortions due to the monopolistic market structure of capital goods would reduce the capital goods price to be equal to the interest rate. This can be achieved by a subsidy of $(1-z_C^M)=\gamma$.

The intersectoral equilibrium condition is

$$w_{HY} = (1 - z_C^M) \frac{\alpha}{\gamma^2} \frac{Ax}{H_Y} r = (1 - z_C^M) \frac{1-\gamma}{\gamma} \delta Ax = w_{HA} . \tag{26}$$

This shows that the intersectoral allocation of human capital is not affected by the subsidy. Therefore, both the equilibrium interest rate and the growth rate remain unchanged. This is due to the fact that human capital allocation does not change despite the decline in opportunity costs of manufacturing capital goods. The latter increases the profitability of manufacturing capital goods instead of consumption goods. This increases demand for capital goods and, together with the unaffected markup (1/γ), raises the monopoly rents, and thus, the wage rate for human capital in R&D. However, this has no effect on the human capital allocation, since the productivity of human capital in manufacturing increases as much as in R&D, due to the higher capital stock. Although no growth effect is induced, the increased capital stock triggers a positive level effect on output (GDP).

Why do the effects of the different subsidies to the monopolistic sector differ? A revenue-enhancing subsidy to capital goods producers not only reduces the relative price of capital goods to consumption goods but also increases the markup $(1/(1+z_R^M)\gamma)$, which leads to a higher price for designs. It is exactly this latter effect that accounts for the induced reallocation. In other words: a revenue-enhancing subsidy helps the monopolists cope not only with the variable costs, but also with the fixed costs stemming from the acquisition of designs. As a result, the monopoly rents are lower after a cost-reducing subsidy than after a revenue-enhancing subsidy. This can be seen by comparing equations (20) and (25). Since in both cases the market price of capital goods is the same, the monoply rents only differ due to the factor $1/(1-z_C^M)$. In other words, since the purchasing power (the monopoly rents) of the capital goods producers is lower than with a revenue-enhancing subsidy, R&D enterprises must be compensated by higher subsidies.

5. Optimal policy mixes

Important policy implications follow from the outcome of the analysis. Since two instruments are needed to cope with two distortions and since the effects of different types of subsidies to monopolistic capital goods producers are not the same, the optimal policy mix depends on how the capital goods subsidy is designed. Table 1 gives an overview of the optimal policy mixes. By choosing an optimal revenue-enhancing subsidy over the capital goods producers $(1+z_R^M=1/\gamma)$, the optimal relative capital goods price can be achieved. By combining this with an R&D subsidy rate of either $1+z_R^A=r/(r-g)$ or $1-z_C^A=(r-g)/r$, the optimal growth rate (equation (13)) can be reached at the same time.

In the case of a subsidy that reduces marginal costs of the capital goods producers, the distorted capital goods price can be corrected. However, no growth effect is induced. With a subsidy rate of $1-z_C^M=\gamma$ the interest rate equals the marginal product of capital goods and the distortion resulting from the market structure of capital goods is eliminated. In order to achieve the optimal growth rate (equation (13)), the R&D sector must be subsidized more heavily, namely according to $1+z_R^A=r/((r-g)\gamma)$ or $1-z_C^A=\gamma(r-g)/r$. This is different from the policy mix discussed previously.

Table 1: Overview of the optimal policy mixes

	Optimal policy mix with a revenue-enhancing subsidy in the manufacturing sector	Optimal policy mix with a cost-reducing subsidy in the manufacturing sector
R&D sector	$1+z_R^A=\frac{1}{1-z_C^A}=\frac{r}{r-g}$	$1+z_R^A=\frac{1}{1-z_C^A}=\frac{r}{r-g}\frac{1}{\gamma}$
Capital goods sector	$1+z_R^M=\frac{1}{\gamma}$	$1-z_C^M=\gamma$

4. Summary and conclusions

Using a Romer-type endogenous growth model the analysis shows that a subsidy linked to revenues can have different growth effects than those from a subsidy linked to marginal costs. This implication of the Romer model depends heavily on the assumed sectoral structure. The result differs from the one of Grossman and Helpman (1991) who show in a slightly different model that a revenue-enhancing subsidy to monopolistic producers does not affect the growth rate or the allocation of human capital. The difference is due to the fact that Grossman and Helpman do not distinguish between capital goods and consumption goods producers.

The analysis also demonstrates that the optimal policy mix depends on how the subsidy to the monopolistic sector is designed. This implies that policy actions may be interdependent so that, when designing one instrument, other policy actions must be considered as well.

References

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