Chapter 13
Knowledge Spillovers and the Timing of Environmental R&D Subsidies

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ABSTRACT Several recent studies have concluded that subsidies for environmentally friendly R&D should be high initially and decline over time. This study shows that scale aspects connected to knowledge spillovers from environmental R&D support the opposite conclusion. Increasing returns to scale in the production of abatement knowledge, as well as an increasing price of carbon emissions, are aspects that favor increasing subsidy rates to firms conducting environmentally friendly R&D.

JEL classification: O32; O38.

KEYWORDS: Environment | Innovation policy | Knowledge spillovers

13.1 INTRODUCTION
The goal of the Paris Agreement is ‘holding the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C’ (UNFCCC, 2015). A major challenge for this goal is to reduce the share of fossil fuels in the energy mix. To keep global warming below 2°C, a third of oil reserves, a half of gas reserves, and more than 80 percent of coal reserves must stay in the ground (McGlade and Ekins, 2015). On the

1. In a recent paper, Millar et al. (2017) are more positive on how much fossil energy can be used to still stay within the target. They show that by limiting cumulative post-2015 CO₂-emissions to about 750 bn tonnes of CO₂, the post-2015 global warming can be limited to less than 0.6°C (temperature increase from 1870 till today is about 0.9°C). Annual emissions at the moment are almost 40 bn tonnes of CO₂, which implies that we will exceed the 1.5°C carbon budget in 19 years if we stay on the current path.
other hand, the IEA (2017) predicts a 30% growth in total energy demand between today and 2040. Hence, the production of clean energy must increase dramatically.

Research and development (R&D) drives down costs and improves technologies, and hence facilitates the diffusion of new, clean technologies. Such technological improvements are considered to be a key element in curbing global warming (see e.g., Carraro et al., 2003; Jaffe et al., 2005). However, innovation markets are inefficient and it is well known that the social returns to R&D may be greater than the private returns to R&D (see e.g. Griliches, 1995; Jones and Williams, 2000; Klette et al., 2000; Bloom et al., 2013). A major reason for this is the public-good nature of knowledge. Knowledge generated from a firm’s R&D activity might spill over to other firms and expand future R&D opportunities, i.e., when developing new ideas we are “standing on the shoulders of giants” (Isaac Newton). The value of these knowledge spillovers are only partly captured by the individual firms, and R&D activity should be subsidized.

There is a recent literature on climate policy and directed technological change that analyzes the timing of subsidies to R&D in clean technologies. Acemoglu et al. (2012) show that clean innovation should be heavily subsidized in early periods and decline over time to induce a switch from dirty to clean technologies. The reason is that the subsidy to clean technologies is used to deal with future environmental externalities when patents have a short lifetime. Greker, Heggedal and Rosendahl (2017) back up the main conclusion on the subsidy path to clean innovation in a model where patents are long-lived and the carbon emission tax perfectly internalizes emission damages. They show that the subsidies to clean innovation should be larger than those to dirty innovation due to knowledge spillovers. Intuitively, climate change necessitates a shift to clean innovation, and when more future researchers innovate on clean technologies than dirty technologies, there will be more researchers standing on the shoulders of a clean innovation done today than of a dirty innovation done today.

We contribute to this literature by analyzing how dynamic aspects of knowledge spillovers, as well as an increasing price of carbon emissions, influence the optimal timing of R&D subsidies to clean technologies, and we find support for the opposite conclusion: Increasing returns to scale in the production of environmental knowledge favor increasing subsidy rates to clean innovation.

We develop a model where the production of new ideas is given by the input of researchers and the stock of knowledge, where the stock of knowledge is a public

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2. A similar argument is made by Acemoglu et al. (2016).
3. A similar argument is made by Hart (2018). See Fischer and Heutel (2013) for a survey over the earlier literature on directed technical change in an environmental context.
good. Patent lifetime is infinite and the social value of a patent is assumed to be identical with the patent price, i.e. the R&D firms appropriate the full value in the market of the technologies they develop. The only externality in the model stems from knowledge spillovers, where knowledge spillovers is defined as the productivity effect following from a change in the knowledge stock. A welfare-maximizing government determines R&D subsidy rates each period to harvest potential welfare gains connected to the positive external effects of these spillovers.

The elasticity of scale of the R&D production function turns out to be crucial in our analysis. The reason is that this elasticity captures a combination of how much R&D productivity increases when the knowledge stock grows, and of how much the market responds to this productivity increase. In fact, in an unregulated economy (i.e., zero subsidies) the elasticity of scale determines whether the production of patents increases over time. Model simulations show that optimal R&D subsidy rates increase (decrease) over time when the elasticity of scale is larger (smaller) than one—holding the price of patents constant over time. When choosing subsidies, the government trades off the costs of using more resources on R&D today against the value of knowledge spillovers from expanding patent production. Expanding the production of patents today increases knowledge spillovers through two channels. First, the expansion directly generates a larger stock of knowledge that increases the productivity of future researchers. Second, R&D firms respond by hiring more researchers in the future and, thus, further increase the generation of knowledge. The value of these knowledge spillovers is the market value of the additional patents generated. The market value is given by the patent price, while the extent of increase in patent production depends on a combination of how much R&D productivity increases and of how many researchers the R&D firms hire—which, again, is given by the elasticity of scale of the R&D production function.

Next, we analyze how changes in the price of carbon emissions affect our results. A common result in the literature on climate change is that the optimal tax on carbon emissions should increase over time as the global warming problem escalates, and thus, the social cost of emissions increases. An increasing price of

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4. The R&D production sector is similar to R&D production in Romer (1990).
5. There is empirical evidence that environmental R&D to some extent crowds out conventional R&D, and that the social returns to environmental R&D may exceed the social returns to R&D in general (see Popp and Newell, 2012; Dechezleprêtre et al., 2017). The present study abstracts from such crowding out effects, and focuses only on mechanisms related to environmental R&D in isolation.
carbon emissions is then incorporated into our model framework by letting the price of environmental patents increase over time. Model simulations show that optimal R&D subsidy rates are increasing over time when the elasticity of scale of the R&D production function equals (or is slightly below) one—when the price of patents increases over time. The reason is that a higher price of patents in a future period implies more future R&D production. When future R&D production is higher, the value of increasing the productivity of R&D goes up, and the government responds by subsidizing R&D more today to build a larger knowledge stock for tomorrow. That is, increasing patent prices exacerbate the knowledge spillovers problem.

Last, model simulations also show that a modest rate of depreciation on the stock of knowledge (due to, for instance, creative destruction), and/or imposing a government budget constraint, do not alter the main results. A drastic rate of depreciation may, however, lead to substantial changes to the above results.

Empirical evidence suggests that it is difficult to pinpoint the elasticity of scale of the environmental R&D production function. Jones (1995, 1999) argues that the return to R&D in general decreases over time as the increase in new knowledge due to a marginal increase in the stock of knowledge is less than one. The scale elasticity, however, also includes the marginal productivity of researchers, and hence, can exceed one even when the marginal returns to the stock of knowledge is less than one. The majority of studies attempting to estimate the environmental R&D production function find that the elasticity of scale exceeds one, see Porter and Stern (2000), Gong et al. (2004), Abdih and Joutz (2005), Pessoa (2005), and Samaniego (2007) for estimates of the elasticity. The future price of carbon emissions is also highly uncertain. However, a large majority of studies predict that the price of carbon emissions will increase as problems connected to global warming escalate. In sum, the empirical evidence, in combination with our simulation results, favors subsidy rates that are increasing over time to firms conducting environmentally friendly R&D.

There are only a few other studies that specifically analyze the timing aspect of spillovers and subsidies to R&D. Grossmann et al. (2010) show that dynamically optimal R&D subsidy rates in general depend on gaps in the stock of knowledge and the capital stock relative to their steady state levels in a model with knowledge spillovers, where the elasticity of scale of R&D production is larger than one, and duplication externalities are included. Heggedal (2015) argues that emerging R&D should be subsidized more heavily compared to mature R&D because the external effect is larger in emerging technologies that grow faster than mature technologies, if the elasticity of scale in R&D production is less than one. Perez-
Sebastian (2007) shows that R&D subsidy rates in general should rise over the transition path towards the balanced growth path within a model with imitation of foreign ideas, as negative externalities connected to imitations gradually decreases.

In an environmental context with increasing carbon taxes, Gerlagh et al. (2009; 2014) show that the optimal R&D subsidy rate to abatement technologies falls over time when patent lifetime is finite. The reason is that there is insufficient support through markets to develop abatement technologies when the price of carbon is low. Heggedal and Jacobsen (2011) find that environmental R&D reforms where subsidy rates are decreasing over time generate the most efficient outcome within a CGE-model of the Norwegian economy.

The paper is organized as follows. The model is laid out in section 13.2, while section 13.3 analyzes the optimal timing of subsidy rates to environmental R&D using simulations. Section 13.4 concludes.

13.2 MODEL

We develop a partial model of the environmental R&D industry to analyze how the externalities from knowledge spillovers affect the optimal distribution of policy incentives across time.7 We assume infinite patent lifetime. Alternative modelling assumptions, like limited patent lifetime or creative destruction, would give a similar relationship between R&D activity today and R&D productivity in the future as in our model. However, such assumptions would create a wedge between the private value and the social value of patents as R&D firms would no longer appropriate the full value in the market of the technologies they develop. We abstract away from such problems in order to focus on knowledge spillovers as a source of underinvestment in R&D. The price of patents may vary over time as the tax on carbon emissions may vary. We assume that the price of patents is positively correlated with the price of carbon emissions, as the value of environmentally friendly technology is likely to be higher when costs of emissions are high.

The production of new varieties is given by the input of researchers and the stock of knowledge, where the stock of knowledge is treated as a public good. An unlimited supply of labor is available for the R&D-sector at the alternative value, which constitutes a fixed wage rate. The productivity of new research projects differs because some new ideas are better than others. There is free entry of profit-

7. We do not model the mechanisms for spillovers between firms. For a discussion on worker mobility as the source of spillovers, see Heggedal, Moen and Preugschat (2017).
maximizing R&D firms, and the firms ignore that their efforts contribute to increase the knowledge stock.

A model designed to fit a typical industrialized country is solved numerically for empirically relevant parameter values; see Porter and Stern (2000), Gong et al. (2004), Abdih and Joutz (2005), Pessoa (2005), and Samaniego (2007). A welfare-maximizing government determines R&D subsidy rates each period to harvest potential welfare gains connected to positive external effects of knowledge spillovers.

13.2.1 TECHNOLOGY

The aggregate production of new patents (knowledge) in environmentally friendly technologies is given by the type of production function that is used in endogenous growth models with horizontal innovation, e.g. Romer (1990), and with vertical innovation, e.g. Aghion and Howitt (1992):

\[ X_t = A_{t-1}^\lambda L_t^\phi, \]  

(1)

where \( X_t \) is the production of patents, \( L_t \) is the labor input, \( \lambda \in [0,1) \) is the output elasticity with respect to labor, \( A_{t-1} \) is the accumulated patents from previous periods, i.e. the stock of knowledge, and \( \phi \) is the output elasticity with respect to patents, i.e. the spillover parameter. The decreasing returns with respect to labor on an aggregate level are motivated by heterogeneous productivity between research projects in the R&D industry. The spillover parameter reflects the effect of the existing knowledge stock on the production of new patents: \( \phi > 1 \) implies increasing returns to knowledge, while \( \phi < 1 \) implies decreasing returns to knowledge. The elasticity of scale in the R&D production function equals \( \phi + \lambda \).

The knowledge stock evolves according to

\[ A_t = A_{t-1} + X_t = \sum_{i=0}^{t} X_i, \]  

(2)

where \( X_0 \) is the initial stock of knowledge.

13.2.2 ENVIRONMENTAL R&D INDUSTRY

Firms in the environmental R&D industry sell patents at a given price. We assume that the price of patents, \( P_p \), are identical for all firms. This price may increase over time as the price of carbon emissions increases over time.
When a patent is produced, the knowledge embedded in the patent is freely available to other firms in future periods, i.e. the knowledge stock is a public good. The firms do not take into account that their patent production influences the productivity of future R&D. This is the source of the knowledge spillover problem.

Further, in each period there is a continuum of research projects with different productivity. The productivity of new research projects differs, and high productivity projects generate more patents per researcher compared to low productivity projects. Individual firms are endowed with private information about one of the new research projects. In each period the firms decide whether to enter the industry and sell the patent to the given price $P_t$.

There is free entry into the industry and the least productive firm to enter earns zero profit, i.e. on an industry level there are decreasing returns to labor. The firms take the wage rate $w$, the unit subsidy rate on labor $z_t$, and $P_t$ as given, and firms enter the industry until

$$P_t \frac{\partial X_t}{\partial L_t} - (w - z_t) = 0,$$

(3)

where $\frac{\partial X_t}{\partial L_t} = \lambda A_t t^{1-\lambda}$ follows from (1). The free entry condition given by (3) can be solved for $L_t$ to get the labor demand in the R&D industry:

$$L_t = \left( \frac{P_t A_t t^{1-\lambda}}{w - z_t} \right)^{\frac{1}{1-\lambda}} \text{ for all } t.$$

(4)

### 13.2.3 GOVERNMENT

A welfare function is absent within this partial model framework. We, however, assume that production efficiency is part of a welfare maximizing solution, where the alternative production value of labor equals the wage rate, $w$. The production value of patents in a period equals the price of patents, $P_t$, multiplied by the number of patents, $X_t$. Hence, the objective of the government consists of maximizing the present value of all future patents minus the alternative cost of labor allocated to the research sector. The policy tools of the government are restricted to R&D subsidy rates $z_t$ in each period. Subsidy rates are chosen to adjust the market solution of labor allocated to the research sector according to equation (4). The subsequent impact on the production of patents is given by equation (1), which influences the knowledge spillover according to equation (2). The government is fully
aware of this interaction between subsidy rates and impacts on knowledge spillovers.

The government maximization problem is:

\[
\max \sum_{t=1}^{\infty} \frac{1}{(1+r)^t} \left( P_t X_t - w L_t \right)
\]

s.t. \( L_t(z_t) > 0 \), (1), (2) and (4),

where \( r \) is the discount rate, i.e. the interest rate. Note that this objective function equals the sum of the surpluses of the producers and the surplus of the government (which equals the negative value of R&D subsidies). R&D subsidies constitute an income transfer between the public and the private sector. Hence, the subsidy term is cancelled from the objective function of the government. The objective function does not include an expression for the consumer surplus, since the social value of a patent is assumed to be identical with the patent price.

The solution to this maximization problem is found by constructing a numerical model that is solved by computer simulations. The numerical model contains all crucial elements described above. A detailed calibration to a specific economy is omitted because the main mechanisms in the model that determine the results are not affected.

A simple example is constructed to illustrate that the scale elasticity is crucial for the development of the knowledge spillovers over time. Consider the unregulated equilibrium where there are no subsidies, i.e. \( z_t = 0 \). Rearranging the first order condition from equation (4) when \( z_t = 0 \) and using (1) gives the production of patents in the unregulated equilibrium as a function of the knowledge stock, \( A_{t-1} \), and the parameters \( P_t, \lambda, w \) and \( \phi \):

\[
X_t = \left( \frac{P_t \lambda}{w} \right)^{\frac{\lambda}{1-\lambda}} A_{t-1}^\phi.
\]

We see that the production function (6) is homogenous of degree \( \frac{\phi}{1-\lambda} \). If \( \phi + \lambda = 1 \), then the production function is homogenous of degree 1, implying constant returns to knowledge on production, i.e. constant spillovers over time. If \( \phi + \lambda < 1 \) (\( \phi + \lambda > 1 \)), then there is decreasing (increasing) returns to knowledge on production, and spillovers decrease (increase) over time. That is, the scale elasticity determines whether the production of patents increases over time, and knowledge spillovers are larger when the future production of patents is larger.
The analytical solution to the government maximization problem is complex because optimal subsidy rates depend on the knowledge stock in all future periods, and vice versa. Thus, we solve the government maximization problem numerically by computer simulations.

13.3 NUMERICAL ANALYSIS

The government maximization problem is solved numerically by computer simulations. Optimal R&D subsidy rates are found by a solver that searches for optimum within the set of feasible combinations of R&D subsidy rates over time. A number of scenarios are simulated to uncover how different parameter combinations \((\phi + \lambda)\) influence optimal R&D subsidy rates over time. We present results for the government problem with specific sets of parameter values that turned out to be crucial for the subsidies. The choice of parameter values may lead to convexity in the objective function, which may exclude a numerical solution. A numerical solution for the government’s optimization problem is obtained by calibrating the initial production of patents by adjusting the wage rate. The exogenous wage rate is adjusted so that the production of new knowledge equals 2.5 per cent of the stock of knowledge. A list of chosen parameter values is presented in appendix A.

The first set of simulation results is presented in Figure 13.1 for different values of the elasticity of scale in the R&D production function. The price of new patents is assumed to be constant in all future periods in these scenarios.

FIGURE 13.1: Optimal subsidy rates with constant patent price
The initial subsidy rate within each scenario is set equal to 100 to facilitate a comparison of scenarios. Figure 13.1 illustrates that the optimal subsidy rates increases (decreases) over time when the elasticity of scale is larger (smaller) than one. Optimal subsidy rates are virtually unchanged when the elasticity of scale equals one. The intuition is that R&D subsidies, which contribute to expand the production of patents, generate two effects. First, the expansion in the production of patents generates a larger future stock of knowledge. Second, the larger future stock of knowledge contributes toward increasing the productivity of future researchers. Future R&D firms respond by hiring more researchers and, thus, further builds the knowledge stock. Both the expansion in the future stock of knowledge and the expansion in the future number of researchers contributes toward increasing the future production of patents, and hence, determine the value of these knowledge spillovers. The elasticity of scale in the R&D production function determines whether the value of these knowledge spillovers expands or contracts as the stock of knowledge grows over time—when the price of new patents is constant over time.

The second set of simulation results is presented in Figure 13.2 for different values of the elasticity of scale in the R&D production function. In these scenarios, the price of new patents is assumed to increase over time due to an increasing price of carbon emissions.
sidy rates increase over time when the elasticity of scale equals one, and when the elasticity of scale exceeds one. Further, the optimal of subsidy rates also increase over time in a case where the elasticity of scale is set slightly below one, while they decrease over time in another case where the elasticity of scale is set even lower (indicated by 1*). The intuition is that the impact of R&D subsidies on knowledge spillovers and production of future patents is identical with the case above, where the price of new patents was assumed to be constant over time. The price of new patents is, however, assumed to increase over time in this case. The value of boosting the production of future patents consequently increases over time. This effect contributes toward generating increasing optimal subsidy rates over time. Hence, this explains why the optimal subsidy rates increase over time when the price of new patents increases over time and the elasticity of scale is set equal to or slightly below one.

The simulation model is constructed with a finite horizon to obtain a numerical solution of the government maximization problem. Knowledge spillovers are limited in later periods by this simplification because the value of knowledge spillovers is reduced to zero in the last period of simulation. We, however, conduct a sensitivity test where we show that an increase in the number of simulation periods from 125 to 150 years only has a marginal impact on optimal R&D subsidy rates for the first 20 years of simulation; see Figure 13.3 where optimal subsidy rates are displayed for these two cases. Hence, we only present and interpret model simulations that are based on the first 20 years of simulation to prevent our results being hampered by the finite horizon. Note that the price of patents is constant over time and the elasticity of scale equals one in both these cases.

![Figure 13.3: Optimal subsidy rates with scale elasticity equal to 1](image-url)
13.3.1 EXTENSIONS

The partial model framework is designed to study the impact of knowledge spillover on the timing of R&D policy. This section extends the model framework to investigate aspects that are omitted in the previous section. First, we investigate implications of introducing a government budget constraint, where the amount allocated to R&D subsidies is restricted. Second, we investigate implications of assuming that old patents become obsolete.

13.3.1.1 Constrained R&D subsidies

Public spending is to a large extent financed by distorting taxes in most countries. Hence, governments are inclined to impose a cost-benefit requirement on public spending that reflects that the marginal cost of public funds exceeds one. We investigate the implications of such a cost-benefit requirement on the timing of R&D policy by imposing a government budget constraint where the amount of public resources allocated to R&D subsidies is restricted. This restriction implies that the government is forced to trade off the benefits of awarding subsidies in one period against the benefits of awarding subsidies in other periods. Model simulations of previous scenarios are conducted with a government budget constraint where the present value of R&D subsidies awarded to R&D firms amounts to 50 percent of the present value of R&D subsidies awarded to firms in previous scenarios without restrictions on public spending. The government budget constraint $BC$ is given by

$$BC = \tau \frac{1}{(1+r)^t} \sum_{t=1}^{T} z_t L_t.$$

The simulations with governmental budget constraints show that the timing of optimal R&D subsidy rates is unaffected by the constraints. The constraints, however, lower optimal subsidy rates in all periods. The intuition is that there is an additional cost connected to awarding R&D subsidies to firms, and that this cost is imposed on subsidies in all periods with equal magnitude. Hence, optimal subsidy profiles are virtually unaffected by the constraint.

13.3.1.2 Creative Destruction

Patents and varieties of goods are likely to become obsolete at some point in time as new and improved innovations emerge. Creative destruction is not incorporated into our main model framework. We, however, shed light on the implications of
this aspect by assuming that obsolete varieties are removed from the stock of knowledge that contributes toward generating new patents. To allow for this, we expand our numerical model to include depreciation of knowledge, represented by a constant rate of depreciation. The function for the knowledge stock is updated to

$$A_t = (1 - \delta)A_{t-1} + X_t,$$

so that

$$A_t = \sum_{i=0}^{t}(1-\delta)^{t-i}X_i,$$

where $\delta$ is the rate of depreciation. Model simulations show that our previous results hold when a modest rate of depreciation is introduced so that the stock of knowledge grows over time. The intuition is that the timing of externalities connected to knowledge spillovers is unaffected, even though the level of externalities is reduced. More drastic rates of depreciation, however, lead to drastic changes in our simulation results. Model simulations show that optimal subsidy rates are constant over time for any elasticity of scale if the production of new patents equals the depreciation of patents, so that the stock of knowledge is constant over time. The intuition is that the government maximization problem becomes identical at the beginning of any period. Thus, the optimal subsidy rate is constant.

Model simulations show that our previous results are completely reversed when a drastic rate of depreciation is introduced so that the stock of knowledge declines over time. The optimal combination of subsidy rates decrease (increase) over time when the elasticity of scale is larger (smaller) than one and the price of patents is constant over time. The intuition is that the stock of knowledge is shrinking. Hence, externalities connected to R&D are shrinking (expanding) with increasing (decreasing) returns scale. Some studies have identified substantial R&D depreciation rates; see Bernstein and Mamuneas (2006) and Mead (2007). A substantial rate of depreciation that leads to a decreasing stock of knowledge does not seem to be empirically relevant as the global warming problem is in an emerging stage.

13.4 CONCLUSION

How governments should engage in policies to spur environmental R&D activity from private firms is an important policy question, since research markets are riddled with inefficiencies. In this paper we explore how one of these inefficiencies—externalities from knowledge spillovers—affects the optimal timing of subsidies for environmental R&D. Model simulations show that optimal R&D subsidy rates
increase (decrease) over time when the elasticity of scale of the R&D production function is larger (smaller) than one—and the price of new patents are constant across time. Model simulations also show that optimal R&D subsidy rates are increasing when the elasticity of scale of the R&D production function equals (or is slightly below) one—and the price of patents increases over time. The majority of the empirical evidence in combination with our simulation results supports the conclusion that subsidies to firms conducting environmentally friendly R&D should increase over time. We also show that a stricter government budget constraint influences the optimal level of R&D subsidies, while the timing issue is unaffected. However, a rate of depreciation on the stock of knowledge may affect the timing of subsidies.

There are some caveats to our conclusion. First, there is no uncertainty in our model. Including a probability of successful innovation would lower the incentives for firms to conduct R&D. Lower R&D activity implies that the social value of increasing the productivity of R&D goes down, and the government would respond by lowering the level of R&D subsidization. If firms get better (worse) at screening R&D projects over time, interpreted as an increase (decrease) in the probability of success, this would increase (decrease) the government’s incentives to subsidize over time. We are not aware of any empirical evidence on whether the probability of success increases or decreases over time.

Second, the empirical literature on output elasticities in the R&D production function is not very well developed. Further research is needed to establish significant ranges for the output elasticities. Third, we have only included one type of externality in the research market. Other externalities, e.g. monopoly pricing and research congestion, may also influence the optimal timing of subsidies to environmental R&D. This is a venue for future research.

REFERENCES


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13.5 APPENDIX A: PARAMETER LIST

The following values were used in all simulations:

\[ A_0 = 500000 \]
\[ P = 1 \]
\[ r = 0.07 \]
\[ T = 125 \]
\[ X_0^{UE} = 12500 \]

UE = Unregulated equilibrium

The tables below show the different parameter values for \( \phi \) and \( \lambda \) that were simulated. The values marked with * are the values used in the Figure 13.1.

Scale elasticity = 1

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<td>0.5*</td>
<td>0.45</td>
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Scale elasticity < 1

\[
\phi \quad 0.05-0.09 \quad 0.1 \quad 0.1-0.54 \quad 0.25 \quad 0.35 \quad 0.4-0.55 \\
\lambda \quad 0.9 \quad 0.25-0.6 \quad 0.45 \quad 0.1-0.25 \quad 0.35 \quad 0.1 \\
\phi \quad 0.45 \quad 0.7 \quad 0.475* \\
\lambda \quad 0.1-0.54 \quad 0.2-0.29 \quad 0.5* \\
\]

Scale elasticity > 1

\[
\phi \quad 0.105 \quad 0.45 \quad 0.56-0.6 \quad 0.525* \quad 0.55 \quad 0.7 \\
\lambda \quad 0.9 \quad 0.56-0.59 \quad 0.45 \quad 0.5* \quad 0.55 \quad 0.31-0.39 \\
\]