Amortizing Securities as a Pareto-Efficient Alternative to Medical Patents

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Purpose and Significance

- I propose a novel reward mechanism to promote monopoly-free innovations.
- This mechanism rewards innovations with amortizing securities rather than patents and the rewarded innovators must place their innovations in the public domain.
- Whoever holds such securities are entitled to time-varying payouts over time, depending on ex post market performance.
- The mechanism can be a Pareto-efficient alternative to medical patents, provided payouts are funded by a head tax.
- The mechanism can overcome a fundamental problem existing in previous prize proposals: Very difficult to determine a lump-sum prize for a new medical innovation in a risky world!

Related Studies

The paper is closely related to the following studies:

- Lump-sum prizes as a patent replacement
  - [Wright, 1983]
  - [Hopenhayn, Llobet, and Mitchell, 2006]
- Modeling vehicle: [Judd, 1985]
- Creative destruction: [Jones, 2000]

A New Way to Incentivize Innovation

- Any innovator is rewarded with a **government-issued innovation-backed amortizing security** rather than with a patent.
- The innovator must agree to place an otherwise exclusive innovation in the public domain so as to render a perfectly competitive market.
- Securities of this sort are tradeable and whoever holds them can receive a stream of time-contingent payouts from the government.
- Funded by a simple head tax, these payouts are calculated using a predetermined payout ratio and the innovative product's overall market sales in a risky world:

$$\boxed{\textbf{payout(t)} = \textbf{payout ratio(t)} \times \textbf{market sales (t)}}$$

- Note that any seller of of the prized product can contribute to the overall market sales.

The Model Economy

- I use a continuous-time dynamic general-equilibrium model to represent the model economy.
- Such a model economy can be seen as a US pharmaceutical industry, or a US economy, or a global economy, depending on how we interpret some model parameters.
- Featuring variety-based innovation resulting from R&D.
- Embeding the new reward system in such a model similar to [Judd, 1985].

Modeling Features

- Consider a closed economy composed of households, manufacturing firms, research firms, and government.
- Households are infinitely lived. They derive utility from consumption of horizontally differentiated products, save foregone consumption to accumulate assets, pay a head tax to fund a public reward system aimed at promoting R&D (research and development).
- Households can earn wages by supplying labor for manufacturing or research activities.

Innovation-backed Amortizing Securities

Definition

(Innovation-backed Securities) These securities refer to a special type of amortizing securities issued by government to reward the innovator at a point in time for a successful innovation. If such a security of vintage τ is legally alive at time $t \geq \tau$, its holder can anticipate from government a risky payout stream $\pi^e(s \mid t)$ for $s \in [t, \tau + \delta)$ according to

$$\pi^e(s \mid t) \equiv \pi^e_\tau(s \mid t) = \mathbb{S}(s \mid t)\pi(s), \tag{1}$$

$$\pi(s) \equiv \pi_\tau(s) = \begin{cases} \theta p(s)x(s), \;\; \tau \in (t-\delta, \, t], \;\; t \geq \tau, \;\; s \in [t, \tau+\delta), \\ 0, \;\; \tau \in (-\infty, \, t-\delta], \end{cases} \tag{2}$$

where

- $\pi^e_\tau(s \mid t)$ denotes the expected instantaneous payout flow to a vintage-τ security at time s, given a time-t information set;
- $\pi_\tau(s)$ is the time-s payout flow to a vintage-τ security;
- t is the present time;
- s is the present time or a future time point;
- τ is the security-issuance date;
- δ is the payout term; θ is the payout ratio;
- $p(s)$ is the time-s price of a typical innovative product;
- $x(s)$ is the time-s quantity of the product sold;
- $p(s)x(s)$ is the product's time-s aggregate market sales;
- $\mathbb{S}(s \mid t) \in [0, 1]$ is the survival function measuring the probability that the product active at time t is to survive to the time point $s \geq t$ so as to earn the contingent payout flow $\theta p(s)x(s)$.

The Survival Function

$$\mathbb{S}(s \mid t) = e^{-\int_t^s \lambda(z)dz} \tag{3}$$

where $\lambda(z) > 0$ is an innovation-based hazard rate at time $z \in [t, s]$, endogenously linked to the economy's aggregate innovation rate, $g(z)$, which will be formulated later.

Innovation and Creative Destruction

The proposed reward system is designed to function to sustain a viable research sector in the decentralized model economy. Such an economy consists of a unit measure of atomistic and symmetric research firms. The representative research firm's production function is assumed to take the form,

$$(1+\psi)\dot{n}(t) = \frac{1}{a} n(t) L_n(t), \quad 0 < \psi, \, a < \infty \tag{4}$$

where $\dot{n}(t) \equiv \frac{\mathrm{d}n(t)}{\mathrm{d}t}$ is a time derivative of the stock of designs (technologies) denoted by $n(t)$ at time t, $L_n(t)$ is the time-t level of labor employment for R&D, a is a technical shift parameter and ψ is a parameter to symbolize the occurrence of Shumpeterian creative destruction; see [Jones, 2000].

Endogenous Hazard Rate

- Equation (4) implies that given the mass of $n(t)$ exiting designs and research input $L_n(t)$ at time t, R&D activities can produce $(1+\psi)\mathrm{d}n(t)$ new designs in an instant $\mathrm{d}t$, while making $\psi\mathrm{d}n(t)$ existing designs obsolete and die right away.
- So, the instantaneous hazard rate, denoted by $\lambda(t)$, at any moment is such that $\lambda(t)\mathrm{d}t = \psi\mathrm{d}n(t)/n(t)$. That is,

$$\lambda(t) = \psi g(t) \tag{5}$$

  where $g \equiv \dot{n}/n$ is an instantaneous innovation rate after taking creative destruction into account.
- We can use $\lambda(t)\mathrm{d}t$ to measure the instantaneous probability that an existing product is to be driven out of the market in an instant $\mathrm{d}t$.

Arbitrage-free conditions

- Research firms hire labor for innovation at a competitive wage, denoted by $w(t)$, at any point in time.
- With symmetries among research firms, we can use $\upsilon(t)$ to represent the common market value of a newly-issued security at time t.
- To each of these firms, $\upsilon(t)$ is the marginal private value of innovation, while $aw(t)/n(t)$ is the marginal private cost of innovation based on (4). Therefore,

$$\upsilon(t) = a\, w(t)/n(t) \tag{6}$$

where $\upsilon(t)$ represents the expected present value of a future payout stream to a typical eligible security holder; that is,

$$\upsilon(t) \equiv \int_t^{t+\delta} e^{-\int_t^s r(z)dz} \mathbb{S}(s \mid t)\pi(s)ds = \int_t^{t+\delta} e^{-\int_t^s [r(z)+\lambda(z)]dz} \pi(s)ds \tag{7}$$

Dynamics of Prized and Unprized Products

- Masses of prized and unprized products:

$$n(t) = n_p(t) + n_{np}(t) \tag{8}$$

- Dynamics: the mass of unprized goods $n_{up}(t)$ evolves according to

$$\dot{n}_{up}(t) = (1+\psi)\dot{n}(t-\delta)\mathbb{S}(t \mid t-\delta). \tag{9}$$

where $\mathbb{S}(t \mid t-\delta) = e^{-\int_{t-\delta}^{t} \lambda(z)dz}$ due to (3).

Fraction of Prized Products

- Let $\zeta(t) \equiv n_p(t)/n(t)$ denote the fraction of prized products.
- We can use (9) to obtain the equation of motion for $\zeta(t)$:

$$\dot{\zeta}(t) = [1 - \zeta(t)]g(t) - (1 + \psi)g(t - \delta)e^{-\int_{t-\delta}^{t}[g(s)+\lambda(s)]ds} \tag{10}$$

- Note that the motion of the fraction of prized goods is subject to:
  - Current-time variables [$\zeta(t)$, g(t)],
  - Lags [$g(s)$, $\lambda(s)$] for $s \in [t - \delta,\ t]$.

Households

$$\max U = \int_0^{\infty} e^{-\rho t} \log u(t)\mathrm{d}t, \quad \rho > 0 \tag{11}$$

subject to

$$u(t) = \left(\int_0^{n(t)} x_i(t)^{\alpha} \right)^{1/\alpha}, \quad \alpha \in (0, 1) \tag{12}$$

$$\dot{A}(t) = r(t)A(t) + w(t)L - T(t) - E(t) \tag{13}$$

- $\rho =$ constant rate of time preference;
- $u(t) =$ CES subutility;
- $A(t) =$ value of financial assets; $r(t)A(t) =$ interest income;
- $w(t)L(t) =$ wage income,
- $T(t) =$ the head tax $= \Pi(t) = \zeta(t)n(t)\pi(t)$;
- $E(t) =$ consumption spending

Aggregate Constraints

- We choose the nominal level of aggregate consumption spending to be the numeraire so that $E(t) = 1$ for $t \in [0, \infty)$ and $r(t) = \rho$ at all times.
- We close the model by presenting two aggregate constraints on consumption expenditure and labor employment:

$$E(t) = p(t)X(t) \tag{14}$$

$$L = X(t) + (1 + \psi)a\,g(t) \tag{15}$$

- where $X(t) = n(t)x(t)$ is aggregate production or manufacturing demand for labor because one unit of output requires one unit of labor input and $(1 + \psi)a\,g(t) \equiv L_n(t)$ is R&D demand for labor in term of (4).

Designing the Shape of Amortizing Securities

- To design optimally the shape of the proposed amortizing securities, we need to derive two steady-state innovation rates:
  - one for the decentralized economy, and
  - the other for the socially planning economy.
- We can then derive the socially-optimal locus (δ, θ) for a given socially-optimal innovation rate. That is,the socially-optimal shape of the proposed amortizing securities is not unique.

The Decentralized Equilibrium Innovation Rate

$$\bar{\upsilon}(t) \equiv \theta\,[\bar{\omega}(t)\cdot E]\int_t^{t+\delta} e^{-(\rho+\bar{\lambda}+\bar{g})(s-t)}\mathrm{d}s = \frac{a}{\bar{n}(t)}\left[\frac{E}{L-(1+\psi)a\bar{g}}\right] \quad (16)$$

or

$$\bar{V} \equiv \bar{n}(t)\bar{\upsilon}(t) = \theta\cdot\left[\frac{1-e^{-\delta(\rho+\bar{\lambda}+\bar{g})}}{\rho+\bar{\lambda}+\bar{g}}\right] = a\cdot\left[\frac{1}{L-(1+\psi)a\bar{g}}\right] \quad (17)$$

where an "overbar" indicates the associated variable's steady-state equilibrium, $\bar{\omega}(t) \equiv 1/\bar{n}(t)$ is a typical firm's steady-state market share, $\bar{\lambda}$ is the steady-state hazard rate based on (5), and $\bar{V}$ is a normalized security value as we scale up a fresh security's market value by $\bar{n}(t)$, which is the mass of existing securities.

Iso-Innovation

- However, (17) is a transcendental equation. So, the equilibrium innovation rate $\bar{g}$ must be solved numerically. More importantly, this equation implies a strictly quasi-concave "iso-innovation" curve on the support of (δ, θ) in the positive quadrant of $\mathbb{R}^2_+$, as given below:

$$h(\delta, \theta \ \mid \bar{g} > 0) \equiv \theta \cdot \left[\frac{1 - e^{-\delta[\rho + (1+\psi)\bar{g}]}}{\rho + (1+\psi)\bar{g}} \right] - a \cdot \left[\frac{1}{L - (1+\psi)a\bar{g}} \right] = 0. \tag{18}$$

- The iso-innovation curve characterized by the equation of $h(\delta, \theta \mid \bar{g} > 0) = 0$ satisfies:
  - (i) $\frac{\partial \theta}{\partial \delta} < 0$ for $\delta, \theta \in (0, \infty)$, $\frac{\partial \theta}{\partial \delta} = 0$ for $\delta \to \infty$, and $\frac{\partial \theta}{\partial \delta} \to \infty$ for $\delta \to 0$;
  - (ii) $\theta \to \theta_{\text{min}} \equiv \frac{a[\rho + (1+\psi)\bar{g}]}{L - (1+\psi)\bar{g}} > 0$ for $\delta \to \infty$; and
  - (iii) $\theta \to \infty$ for $\delta \to 0^+$.

The socially optimal innovation rate

To obtain the socially optimal steady state, we assume a social-planning economy whose social planner is to maximize the current-value Hamiltonian,

$$\max_{g(t)} \mathcal{H} \equiv \left[\frac{1-\alpha}{\alpha}\right] \log n(t) + \log[L - (1+\psi)g(t)] + \mu(t)[n(t)g(t)] \quad (19)$$

$$s.t.: \quad \lim_{t\to\infty} e^{-\rho t}\mu(t)n(t) = 0 \quad (20)$$

where $g(t)$ is a control variable, $n(t)$ is a state variable, $\mu(t)$ is the costate variable measuring the shadow value of a new variety under the social-planning regime, and (20) is the transversality condition.

The socially optimal innovation rate, cont.

Maximizing the Hamiltonian, we can obtain the socially optimal innovation rate $\bar{g}^{SP}$ according to

$$\bar{V}^{SP} \equiv \bar{n}^{SP}(t)\bar{\mu}^{SP}(t) \equiv \left[\frac{1-\alpha}{\alpha}\right] \cdot \left[\frac{1}{\rho}\right] = (1+\psi)a \cdot \left[\frac{1}{L-(1+\psi)a\bar{g}^{SP}}\right] \tag{21}$$

where

- $\left[\frac{1-\alpha}{\alpha}\right] \cdot \left[\frac{1}{\rho}\right]$ is the normalized marginal social value of a new variety, and
- $(1+\psi)a \cdot \left[\frac{1}{L-(1+\psi)a\bar{g}^{SP}}\right]$ is the normalized marginal social cost.

The socially optimal innovation rate, cont.

- Solving the equilibrium condition (21), we can obtain the socially optimal innovation rate,

$$\bar{g}^{SP} = \frac{L}{(1+\psi)a} - \left(\frac{\alpha}{1-\alpha}\right)\rho \tag{22}$$

- Implications:
  - (1) a larger the labor force (i.e. larger L) or a higher research productivity (i.e. smaller a) can sustain a larger Pareto-optimal innovation rate, reflecting the model's scale-effect feature.
  - However, the Pareto-optimal innovation rate becomes smaller if there is a larger hazard of creative destruction (i.e. larger ψ), or if there is a larger degree of product similarity (i.e. larger α), or if households have a stronger degree of time preference (i.e. larger ρ).
  - All these relationships make logical sense from the social perspective.

The Socially optimal shape of amortizing securities

- By forcing the decentralized equilibrium innovation rate $\bar{g}$ to match the socially-optimal level $\bar{g}^{SP}$, we can compute any of the infinitely many combinations of a typical amortizing security's payout ratio and term based on (18).
- Using a benchmark parameter set ($\rho = 0.07$, $\alpha = 0.8$, $L = 1$, $a = 1.5$, and $\psi = 1$), we compute the optimal shape of innovation-backed securities, as shown in the following Figure, where the middle locus corresponds to the benchmark coefficient of creative destruction ($\psi = 1$) and two other scenarios for robustness checks on this coefficient.

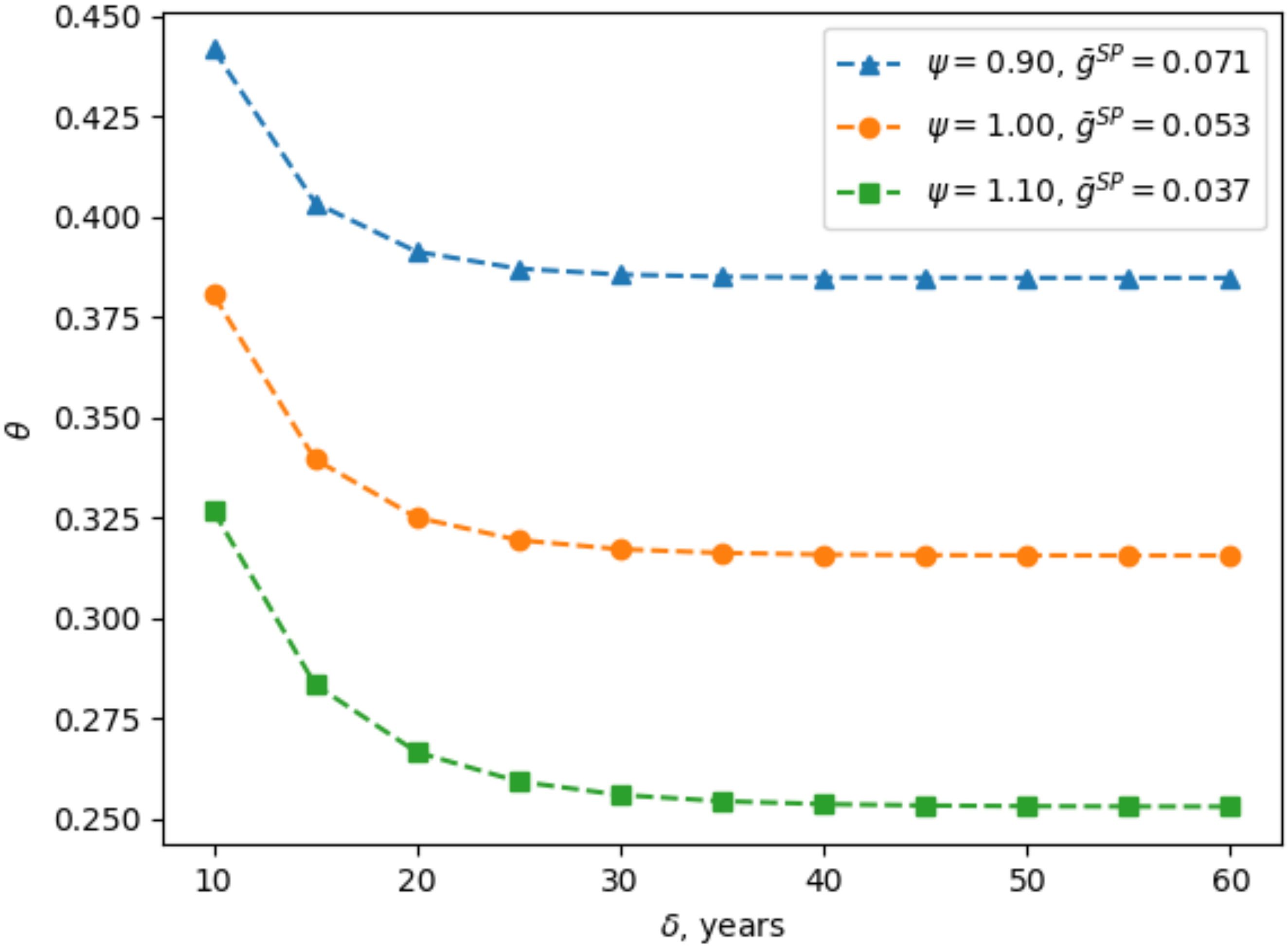

Figure: **The socially optimal loci of payout term and payout ratio**

The head tax for aggregate payouts

I chose a non-distortionary head tax to fund the public-reward system with amortizing securities. I assume that the collected head tax exactly matches the reward system's aggregate payouts at all times. It is important to see how the tax burden falls on US taxpayers. I can measure the tax burden using the following formula:

$$\bar{\tau} \equiv \frac{\bar{T}}{\bar{Y}} = \frac{\bar{\Pi}}{\bar{Y}} = \theta \left[1 - \frac{(1+\psi)a\bar{g}}{L} \right] \bar{\zeta} \tag{23}$$

$$TaxBurden \equiv \frac{\bar{T}}{GDP}$$

$$= \left(\frac{\bar{T}}{\bar{Y}} \right) \times \left(\frac{\bar{Y}}{G\bar{D}P} \right) \tag{24}$$

$$= \bar{\tau} \times (\text{Size of Pharm. Industry in US Economy})$$

US Phamaceutical: R&D Intensity

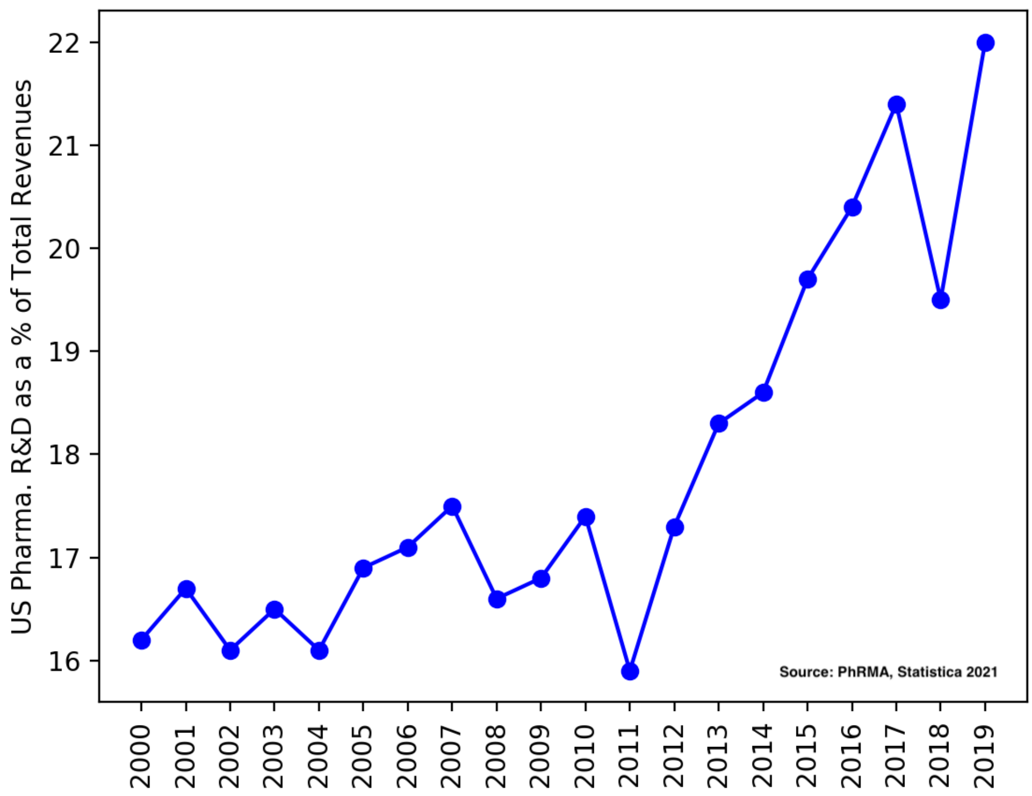

Figure: **US Phamaceutical R&D in Sales**

The Tax Burden of Replacing Medical Patents

Table 1: Tax Burden of Benchmark Scenario with Payout Term of 20 years

	Case 1: $\psi = 0.9$	Case 2: $\psi = 1.00$	Case 3: $\psi = 1.10$
Payout Term, δ^{SP}	20 yrs	20 yrs	20yrs
Payout Ratio, θ^{SP}	39%	33%	27%
Payouts/Pharm. Sales	27%	21%	13%
Tax Burden on US Economy	1.08%	0.84%	0.52%

Table 2: Tax Burden of "Short" Scenario with Payout Term of 10 years

	Case 1: $\psi = 0.9$	Case 2: $\psi = 1.00$	Case 3: $\psi = 1.10$
Payout Term, δ^{SP}	20 yrs **10 yrs**	20 yrs	20yrs
Payout Ratio, θ^{SP}	44%	38%	33%
Payouts/Pharm. Sales	18%	10%	1%
Tax Burden on US Economy	0.72%	0.4%	0.04%

Table 3: Tax Burden of "Long" Scenario with Payout Term of 50 years

	Case 1: $\psi = 0.9$	Case 2: $\psi = 1.00$	Case 3: $\psi = 1.10$
Payout Term, δ^{SP}	20 yrs	20 yrs	20yrs
Payout Ratio, θ^{SP}	38%	32%	25%
Payouts/Pharm. Sales	31%	26%	21%
Tax Burden on US Economy	1.24%	1.04%	0.84%

Figure: **The Tax Burden**

Concluding Remarks

- This paper proposes a novel public reward system and its advantage is threefold:
  - First, it can ensure perfectly competitive diffusion of innovative products while maintaining a pro-innovation mechanism for sustainable marcoeconomic growth.
  - Second, the prize for innovation is an innovation-backed security rather than a lump-sum prize, thereby precluding the need to incur any up-front cost to taxpayers as soon as a successful innovation arrives.
  - Third, since payouts are distributed based on a product's market performance, the risk of miscalculating the value of a new innovation as a lump-sum prize can be eliminated.
- Enforcing compulsory marginal-cost pricing.
- Spliting an amortizing security into shares.

References I

Hopenhayn, H., G. Llobet, and M. Mitchell. (2006)
Rewarding sequential innovators: Prizes, patents, and buyouts.
Journal of Political Economy 114, 1041-1068.

Jones, C. I. and J. C. Williams (2000)
Too much of a good thing? the economics of investment in R&D.
Journal of Economic Growth 5, 65–85.

Judd, K. L. (1985)
On the performance of patents.
Econometrica 53, 567–585 (1985).

Wright, B. D. (1983)
The economics of invention incentives: patents, prizes, and research contracts.
American Economic Review 73, 691–707.

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