Ideas-Driven Endogenous Growth and Standard-Essential Patents

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Abstract

In this paper, we study the impact of standard-essential status for patents on production possibilities of the economy and long-term growth. As we show, the innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Moreover, when the discovery rate of new technologies is smaller than the discounting rate of the monopoly profits, standards and standard-essential patents tend to be growth-reducing, despite a conjectured positive contribution of standards to the marginal productivity of human capital. Market failures associated with patent abuse have been treated historically by various measures ranging from compulsory licensing to imposing reasonable and non-discriminatory (FRAND) pricing on essential technologies. We show that mandated compulsory licensing has a negative impact on long-term growth, while a voluntary FRAND pricing together with faster rates of follow-up innovations may be growth-enhancing.

Keywords: standard-essential patents, technology innovation, endogenous growth.

JEL Codes: O33, O34, O41.

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Introduction

In this paper, we study how standards-essential patents and their pricing mechanisms impact the long-term economic growth. Standards-essential patents (SEPs), where patent holders apply "essential" intellectual property (IP) to an emerging standard as explained in more detail below, is a phenomenon that has been taking on exponentially increasing importance over the last two decades (see Figure 1). This growth is likely related to the growing complexity of high-tech devices, hardware, and telecommunications products and services. They incorporate more and more technologies to make them work well, miniaturization of components in technological systems, as well as industry "deconstruction" where firms become less vertically integrated and produce fewer parts of a more modular system, relying on interfaces developed with partners. In this article, we analyze the economics of SEPs from a macroeconomic point of view, the incentives for participating in the production of technology with standards versus the final good production, under what circumstances standards enhance economic growth, and the consequences of the IP licensing terms for economic growth.

We model the endogenous technological change as in Romer [1990] and extend it to talk about standardization of technologies and standard-essential patents. We embed in a macro-model the interaction between two novel stock variables: patented ideas and standard-essential patents. We add a dynamic interaction between patented ideas and standard-essential patents and model how standard-essential patents emerge over time from patented ideas. The key to our dynamics is an observation that standardization of individual technologies occurs at some random points in time, i.e. that it is not exactly known which patents would become future standards. Yet, importantly, we show that in the long run both patents and standards grow at the same rate and so we can focus on balanced-growth equilibrium. As more and more patents become part of a standard and receive special treatment as standard-essential patents, they have the potential to become platforms for future innovation and create a possibility for accelerating economic growth.

In principle, we can plug in our dynamic model of the contribution of patented ideas and standard-essential patents to total factor productivity into a macro-model of any type. In our current working paper, we introduce standard-essential patents into the canonical endogenous growth model of Romer [1990]. Our research questions are how standardization of patents affects economic growth; whether standardization is growth-enhancing or not; and how regulation of pricing under standard-essential patents interferes with economic growth. Households choose between two sectors of the economy: the innovative sector and the final-good sector. Their endogenous choice drives the growth rate of the economy in the long run, and relative incentives depend on the productivity of standard-essential patents, the rate of standardization, the discount rate, applied to monopoly profits, among other parameters in the model.

Market failures associated with patent abuse have been treated historically by various measures ranging from compulsory licensing to imposing Fair, Reasonable and Non-Discriminatory (FRAND) pricing on essential technologies. As we show, the innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Thus many of these measures, which reduce the monopoly rents for patent owners, may have a negative impact on long-term growth. However, this finding assumes no change in the rates of further and follow-up innovation after the standard is set. In an extension of our model, in which every standard brings a number of additional patents as a follow-up innovation, the long-term growth increases with standardization.

There has been a growing research interest in the process of standardization and standard-essential patents. Lerner and Tirole [2015] develop a seminal theoretical framework to study the optimal standard composition and incentives of end-users to implement a standard technology with competitive price commitments. In particular, they show how standards are often are inefficiently small (under-inclusive) and how the SSOs create competition among owners of technology and lower licensing fees. In our paper we take the composition of a standard as given and focus on the long-term growth dynamics. In this sense, we complement the analysis in Lerner and Tirole [2015] with a macro-view on standards and the regulation of licensing fees. Kung and Schmid [2015] study the asset-pricing consequences of innovation and patenting in a general equilibrium macroeconomic setting. We complement their analysis by bringing standardization process of patents into the relatively standard macro environment and focusing on long-term growth rather than short-term business cycle. Our model of innovation is different from Gârleanu and Panageas [2017], who use labor instead of human capital as the main factor to pin down the growth rate of the economy. Standards will not play much role in a setting like Gârleanu and Panageas [2017] because the trade-off for suppliers of labor does not fully take into account the present value of monopoly profits coming from patents, like in Romer [1990] setting.

Standardization and SEPs received a relatively broader coverage in the empirical studies. In Blind and Thumm [2004] authors model the probability of a patent holder joining the standardization processes. They demonstrate that companies with higher patenting intensities are less likely to join standardization race. The intuition behind these results is that a company with a high patenting intensity possesses a strong technological advantage that yields market success without the support of formal standardization. Blind and Thumm [2004] discuss incentives and deterrents of firms to join standardization process. On the one hand, the decision to apply for a standard might be driven by the economies of scales (diffusion of well-protected know-how) and positive network externalities. On the other hand, companies may be reluctant to spread their technologies as they seek a dominant position in the market and exclude others from having access to their unique technologies. The results suggest that the positive economic effects of standards will not be fully exploited because big technological companies are still reluctant to participate in standardization.

In a comprehensive report, OECD [2013] describes SSOs, how they work to develop new knowledge, and how standards can contribute to innovation. According to OECD, SSOs have to strike a delicate balance between what we are calling the IP holders or the "supply-side" of technology and the "demand side" of potential adopters. FRAND terms are seen as a potential solution to hold-up problems, although the authors acknowledge the lack of commitment once IP holders pledge to adhere to FRAND terms and the problems this can cause. Hold-up is only one problem associated with "thicketed" technology spaces such as technology standards, and the other is "royalty stacking." Both of these may lead to costs that greatly outweigh the benefit from adopting or commercializing the standard OECD [2013].

Bekkers and Updegrove [2012] provide an extensive treatment of the interrelations between IP and standards and the challenges of IP rights in standards. The authors describe the workings of several well-known SSOs and the difficulties of combining different IP claims in a standard. They stay at the level of "IP" because patents may be only one form of IP critical to conform to a standard without infringing on it. The definition of what "essential" means varies widely from SSO to SSO, with large variation in practices across many areas. Relevant practices are whether to include copyrights and other non-patent IP, whether the "essentiality" includes commercial or purely technical, whether the timing of essentiality is defined, whether pending applications are included, whether expired or invalid patents are included, and several more.

The paper is organized as follows. Section 1 describes the mechanics of technological standardization and demonstrates exponential growth of the stock of SEPs. Section 2 develops the theoretical model of endogenous balanced growth with patents and standards. Section 3 discusses policy implications, reasonable pricing, and the regulation of mark-ups in the context of our theoretical model. Section 4 concludes.

1 Standard-Essential Patents

A standard is a description of an interface (e.g., a plug and socket for electricity or audio component connection), a technical specification (e.g., wifi connectivity), a "dominant design" in a marketplace (e.g., DVD format, or historically, internal combustion engine automobile), or a way of doing things (e.g., driving on the right side of the road). These are not mutually exclusive, and there can be different ways of developing and commercializing them. In this article, we will focus primarily on the first three, with an emphasis on the established norms in a technical system.

How do standards come into force? Standards are normally classified as de facto and de jure. De facto standards are usually developed and commercialized by private parties, for example, firms, either in a private consortium or even individually, introduced into the market and then accepted by the market. The firm may or may not coordinate the development of the standard with other parties, what is important is that the de facto standard is a standard in use and its claim to legitimacy is that the market finds it useful. A de jure standard, on the other hand, is something that is intentionally negotiated by a third party, which is often called a "standards-setting organization" (SSO) or a "standards committee." Examples of SSOs include the IEEE (Institute of Electrical and Electronics Engineers), ISO (International Organization for Standardization), or ITU (International Telecommunications Union). These bodies coordinate the development of standards by managing the various parties to determine the functionality of the standard, the technical specifications, and the interfaces needed to comply with and use the standard.

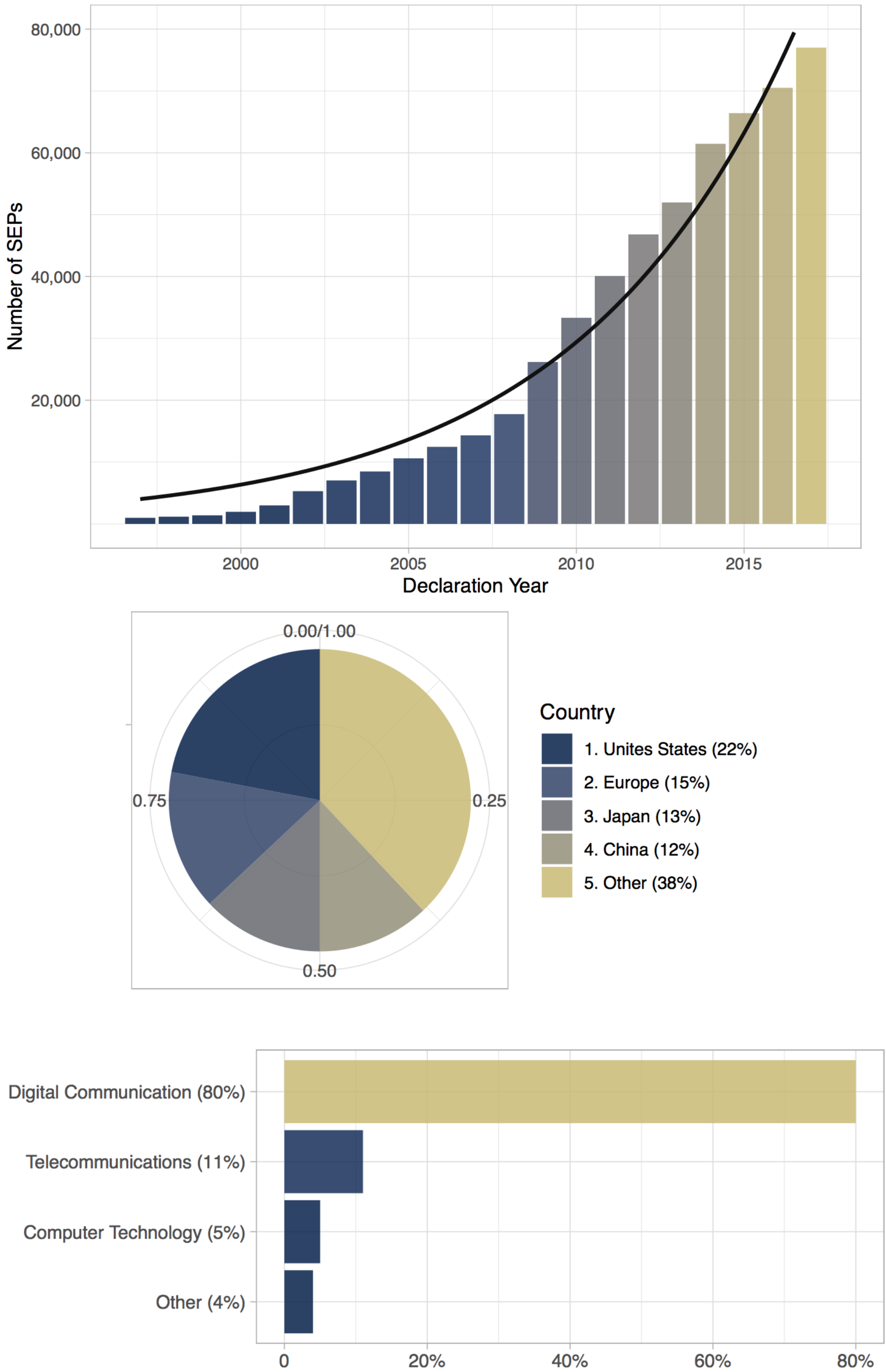
One apparent complication of the standard-setting process described above is that with increasing complexity, there are more parties involved in setting the standards, and these parties may or may not bring IP that is owned by them and that will be crucial for complying with the standard. If a third party would like to adopt the standard, the third party would have to negotiate a license agreement with every IP holder involved in the standard; otherwise, the third party would be an infringement of some IP in the standard. In some cases, there are dozens or even hundreds of IP owners staking some claim to the IP of the standard and this negotiation process would become lengthy and expensive. Furthermore, it is not clear that an IP holder would even grant a license at any price, or threaten to withhold a license. Therefore, in such a situation, potential adopters would be highly unlikely to adopt the standard and thus in the extreme case none of the IP holders would receive royalties for their technologies.

Such examples of patent abuse have a long history since the 18th century and one of the oldest governmental response has been compulsory licensing. Under compulsory licensing scheme the government or the regulatory body grants a license the the IP user at some reasonable price often predetermined in a court ruling. The IP holder loses full protection of the IP and the associated monopoly mark-up. These measures have been profound in the context of public healthcare systems to ensure continuous availability of essential drugs (Son [2019]). Compulsory licensing is an extreme example of "fair and reasonable" pricing, which entails very little negotiation with the IP holder once implemented.

The policy of treating standard-essential patents (also called "essential patents") was developed in recent years to deal with the standard-specific situation of patent abuse. SEPs are patents that are required for a third party to comply with a given standard (Tucci [2013]). The IP holders promise to charge "fair and reasonable" license fees, and to do so in a "non-discriminatory" way; in other words, to not deny anyone who wants a license to have one. Such pricing is called "FRAND" terms for Fair, Reasonable, And Non-Discriminatory. The argument goes that an IP holder trades off FRAND terms in exchange for a higher likelihood of adoption of the standard since if no-one adheres to FRAND, the standard ends up in a prisoners-dilemma-type problem and no-one profits from the adoption of the standard as described above. In practice, the details of FRAND terms are not negotiated in advance and are only solved by negotiation and litigation. There has been attempts to make the price setting mechanism for SEPs more efficient, for example see Lemley and Shapiro [2013].

Our data on standard-essential patents (SEPs) covers 80,935 patents with application years spanning 1995 to 2017 provided by the IP-lytics. Out of all patents published Figure 1 shows the distribution of patents applied for in different years. As seen in that figure, SEPs represent a phenomenon of growing importance for the economy. 22% of patents were published by the US patent office, 15% of patents were published by the European patent office, these are the two biggest patent offices in our data. All the SEPs in our data belong to electrical engineering sector and cover a variety of industry fields. Digital communication, telecommunication, and computer technology are the three most populated industry fields in our data.

Figure 1: Stock of SEPs by declaration year, country, and patent type



Legend: The first panel of the figure shows the total number of declared standard-essential patents grouped by the declaration year. Black line shows the exponential fit of the data. The pie chart shows the ratio of standard-essential patents granted by patent offices of different countries. The last panel of the figure shows the percentage of different industry types among the SEPs.

2 The Model

In this section, we describe our theoretical framework to study the effect of standardization on innovation and economic growth. We describe agents who produce innovation—innovators, the process of technological change and formalize the notion of technological standardization. Standardization of a technology results in a substantial increase in the economy-wide demand for that technology. For example, when JPEG became a standard image format, most producers of photo cameras moved to JPEG and abandoned alternative formats of image encoding. Our idea, in brief, is that technologies become standard-essential over time at some rate and standardization of one technology crowds-out demand for a set of rival technologies. Innovators are running a risk of their patents becoming irrelevant for the production process if a competing technology is standardized.

2.1 Innovators and technological change

We model the endogenous technological change as in Romer [1990] and extend it to include standardization of technologies and standard-essential patents. In our model, the economy is populated by a fixed number of agents $H = 1$, which represents the stock of human capital. A subset of agents H_A decide to be innovators and the remaining $1 - H_A$ agents contribute their human capital to final good production. Economic growth is endogenously driven by decisions of agents to become innovators—as more agents choose to be among H_A in equilibrium, economy grows at a higher rate.

As in Romer [1990], there is a separation between the "rival component of knowledge", H, and the "nonrival, technological component", A, both of which are "excludable" factors of production. We model A as discoverable patentable technologies. Time runs continuously and at every point in time $t \geq 0$ a patentable technology arrives to an innovator as a random event with a Poisson rate $\kappa \cdot A_t$. The growth rate of the stock of discovered patented technologies A_t is:

$$\frac{dA_t}{A_t} = \kappa \cdot H_A \cdot dt \tag{1}$$

According to the equation (1), the discovery of technologies exhibits increasing returns to scale driving the growth of the economy.

In addition, we assume that at some point in time an individual patented technology may be included in a standard. We denote industry standards by $A_{sep,t}$ and, as we discuss later, each standard includes $N > 1$ individual patented technologies in it. We denote the technologies that have not been included in a standard by $B_t < A_t$. The accounting identity for all technologies is:

$$A_t = N \cdot A_{sep,t} + B_t \tag{2}$$

The stock of discovered technologies A_t enhances the production of the final good Y_t, which is consumed by households. To focus our analysis of economic growth on the role of human capital H_A and productive technologies A_t we use a parsimonious production function of the final good Y[1]:

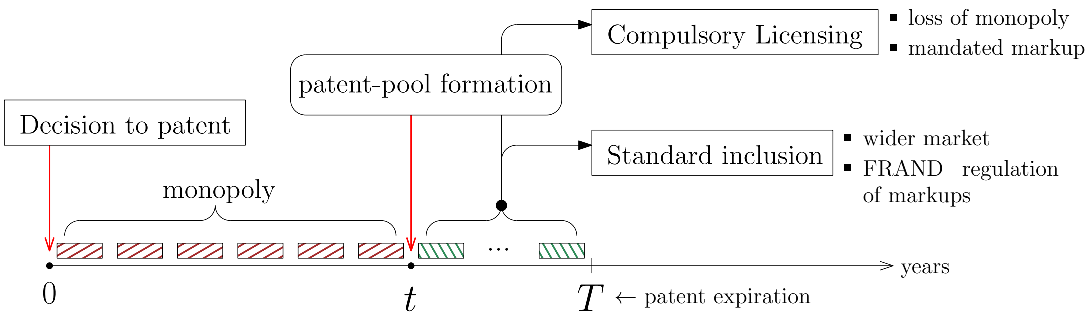
$$Y_t = (1 - H_A)^{\alpha} \left(\int_{i \in B_t} x_{i,t}^{1-\alpha} \, di + (1 + \epsilon_{sep}) \cdot \int_{j \in N \cdot A_{sep,t}} x_{j,t}^{1-\alpha} \, dj \right) \tag{3}$$

Each individual technology in B_t is used to produce an intermediate good x_i, which enters the production function as an input and has diminishing returns to it. Each industry standard in $A_{sep,t}$ is used to produce N intermediate goods x_j, which all enter the production function as inputs with diminishing returns. Further, we assume standardization itself has some additional effect on the total factor productivity, so we put an extra $(1 + \epsilon_{sep})$ term for all the inputs which are produced under standards. The marginal productivity of standardized technology is:

$$\frac{\partial Y}{\partial x_{j \in N \cdot A_{sep,t}}} = (1 + \epsilon_{sep}) \frac{\partial Y}{\partial x_{i \in B_t}}$$

[1] As in Romer [1990] the results on the endogenous growth are not affected by changes in labor supply. Governed by this insight we implicitly assume a perfectly inelastic labor supply $L = 1$ and focus our analysis on the effect of human capital allocation on long-term growth.

Figure 2: The lifetime of a patent in the model



When standardization has a positive effect on the total factor productivity, $\epsilon_{sep} > 0$, the marginal product of standardized technology is higher. Alternatively, standardization may have no effect or a negative effect on the total factor productivity, $\epsilon_{sep} \leq 0$. We discuss the role of these alternative assumptions in detail in our analysis.

2.2 Patents

A successfully granted patent gives the innovator a monopoly right in production of an intermediate good, which is valuable in the final good production process. The patent expires after $T = +\infty$ years, which is a normalization—a finite patent life would not affect our qualitative results.

Each patent i has value P_B and it allows to produce an input x_i. In the future life of a patent two events may happen: A new relevant standard may encapsulate a patent, or a new standard may make it obsolete. Before either of these events the inventor enjoys a monopoly right to produce x_i. The inverse demand for x_i from the final good production sector has a constant price-elasticity:

$$p(x_i) = \chi \cdot x_i^{-\alpha} \tag{4}$$
$$\text{where:} \qquad \chi = (1-\alpha)(1-H_A)^{\alpha}$$

The unit cost of production of input x_i is the cost of capital $r(t)$ times the amount of capital needed η. The optimal monopolistic price $p^M(t)$ and the monopolistic output of the input $\overline{x}_i$ every period is:

$$
\begin{aligned}
p^M(t) &= \frac{r(t)\cdot\eta}{(1-\alpha)} \\
\overline{x}_i &= (1-H_A)\cdot\left(\frac{r(t)\cdot\eta}{(1-\alpha)^2}\right)^{-\frac{1}{\alpha}}
\end{aligned}
\tag{5}
$$

The monopoly profit per unit of time is:

$$
\pi^M(t) = \alpha\cdot(1-\alpha)(1-H_A)\left(\frac{(1-\alpha)^2}{r(t)\cdot\eta}\right)^{\frac{1}{\alpha}-1} \tag{6}
$$

This expression is the monopoly profit of a patent that has been successfully granted, and has not been included in any standard. Moreover, no existing standard replaced the productive role of this patent. Assuming the instantaneous likelihood of a zero-markup compulsory licensing of the patent is γ_{cl}, the value of patent i is:

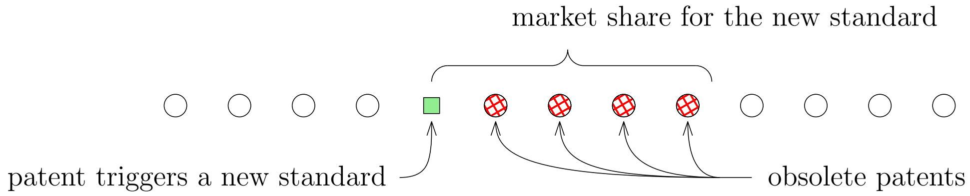
$$
P_B = \pi^M(t)/(r(t)+\gamma_{cl}) \tag{7}
$$

What happens with standardization we describe in the next subsection.

2.3 Standards

At an exogenous rate γ_{sep} an individual patent wins a standardization race with the standard-setting organization. In our model, γ_{sep} is the i.i.d. Poisson intensity of this event happening to an individual patent. Once it becomes a standard, it consumes the market share of $N-1$ other technologies. We refer to N as the scope of a standard in the economy: One standardized technology substitutes $N-1$ individual rival technologies, which become obsolete when a standard is approved by the standard-setting organization. For example, in case of JPEG the scope N would equal one plus the number of alternative image encoding technologies that lose their market share in favor of JPEG when it becomes an industry standard.

Figure 3: Standardization of patents



The event with rate γ_{jpeg} has occurred to the patent marked by a green box. The scope of a new standard is $N = 5$, so the winning patent eats the market share of the $N - 1 = 4$ other patents that used to protect a sufficiently similar technology.

The growth in the stock of standard technologies $A_{sep,t}$ over time is:

$$\frac{dA_{sep,t}}{dt} = \gamma_{sep} \cdot B_t \tag{8}$$

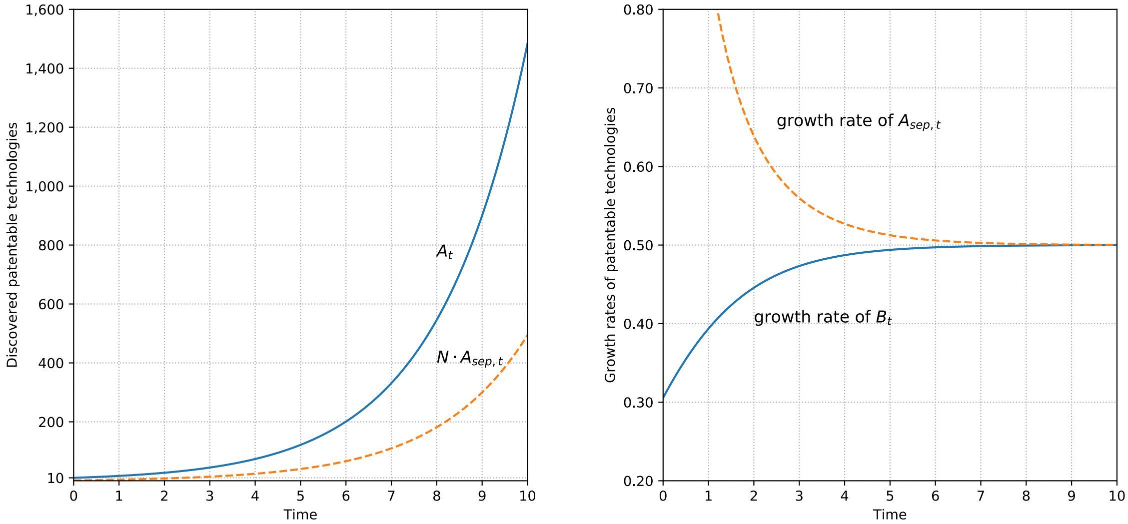
This results in the dynamics for individual patents not included in a standard:

$$\frac{dB_t}{dt} = \kappa \cdot A_t \cdot H_A - N \cdot \gamma_{sep} \cdot B_t \tag{9}$$

When there are no standards and $A_{sep,t} = 0$ we have $A_t = B_t$ and the growth in newly-set standards is $\dot{A}_{sep,t}/A_{sep,t} = \gamma_{sep}$. As standards cover all discovered technologies so that $A_{sep,t} = A_t/N$ we have no individual patents remaining $B_t = 0$ and the growth in standards stops $\dot{A}_{sep,t}/A_{sep,t} = 0$. In the balanced growth equilibrium there could be a steady-state situation when the growth in standards is equal to the growth in patents and is equal to the overall growth of technological discovery $\kappa \cdot H_A$. Note that H_A is endogenous.

Now we explore how standardization affects the value of a patent P_B. Suppose the standardization event occurs and the owner of the patent enjoys the extended market share $N > 1$ and the contribution of standardization to productivity $(1 + \epsilon_{sep})$. The

Figure 4: Growth in standards: Example



Dashed line shows standard-essential patents $N \cdot A_{sep,t}$, solid line shows the stock of discovered technologies A_t. In the beginning there are $A_0 = 10$ technologies and $B_0 = 9$ individual patents. The rate of standardization $\gamma_{sep} = 0.05$, the scope of standards is $N = 5$ and the parameters of technological growth are $\kappa = 0.5$ and $H_A = 1$. The figures show how the growth rates in technologies, standards and individual patents all converge to $\kappa \cdot H_A = 0.5$.

per-unit demand for the resulting input x_j is:

$$p(x_j) = \overline{\chi} \cdot x_j^{-\alpha} \tag{10}$$

$$\text{where:} \quad \overline{\chi} = (1 + \epsilon_{sep})(1 - \alpha)(1 - H_A)^{\alpha}$$

The unit cost of production of input x_j is the cost of capital $r(t)$ times the amount of capital needed η. The optimal monopolistic price is still the same because we assume there is no change in the demand elasticity, however the monopolistic output of the input $\overline{x}_j$ per unit of time changes to:

$$\overline{x}_j = \overline{x}_i \cdot (1 + \epsilon_{sep})^{\frac{1}{\alpha}}$$

The monopoly profit per unit of time becomes:

$$\pi_{sep}^{M}(t) = N \cdot (1+\epsilon_{sep})^{\frac{1}{\alpha}} \pi^{M}(t) \tag{11}$$

Let the inter-temporal cost of capital be $r(t)$. The HJB equation for the value of an individual patent P_B before standardization implies:

$$(r(t) + N \cdot \gamma_{sep} + \gamma_{cl}) \cdot P_B = \pi^{M}(t) + \underbrace{\gamma_{sep}\left(\frac{\pi_{sep}^{M}(t)}{r(t)}\right)}_{\text{set as a new standard}} + \underbrace{(N-1)\gamma_{sep} \cdot 0}_{\text{eaten by a new standard}}$$

$$P_B = \frac{\pi^{M}(t)}{r(t)} \cdot \frac{r(t) + N \cdot \gamma_{sep}}{r(t) + N \cdot \gamma_{sep} + \gamma_{cl}} \cdot \left(\rho(t) + (1-\rho(t))(1+\epsilon_{sep})^{\frac{1}{\alpha}}\right) \tag{12}$$
$$\text{where: } \rho(t) = \frac{r(t)}{r(t) + N \cdot \gamma_{sep}}$$

There are several economic insights that come out of the last equation. When $\epsilon_{sep} = 0$, i.e., there is no contribution of standardization to productivity due to standardization, the monopolist gets the same expected profits as if there is no standardization in equation (7). However, when $\epsilon_{sep} = 0$ there is a redistribution of market shares in the production of different intermediate goods. Each monopolist ex ante faces $\gamma_{sep}/(N-1)\gamma_{sep}$ odds of winning the N times larger market and the residual odds of losing business. In expectation, this market share effect does not affect incentives. Only when $\epsilon_{sep} \neq 0$ standardization may change the incentives that drive technological innovation.

2.4 Balanced growth equilibrium

We are primarily interested in the balanced growth equilibrium of the model, in which the economy grows at a constant rate. According to the equation (3), the growth rate is determined by: 1) the productivity of human capital in the innovative sector relative to the final good production sector, and 2) the dynamics of standardization of patents and the contribution of standardization to productivity ϵ_{sep}.

From our previous discussion recall the dynamics of standard-essential patents and all other patents over time:

$$\frac{dA_{sep,t}}{dt} = \gamma_{sep} \cdot B_t \quad \text{and} \quad \frac{dB_t}{dt} = \kappa \cdot A_t \cdot H_A - N \cdot \gamma_{sep} \cdot B_t \tag{13}$$

Substitute for the stock of discovered technologies the total sum of patents and established standards by using the accounting identity in the equation (2). The system of equations below capture the time-dynamics of the stock of patents and the stock of standards:

$$\begin{aligned} \frac{dB_t}{dt} &= (\kappa \cdot H_A - N \cdot \gamma_{sep}) \cdot B_t + \kappa \cdot H_A \cdot N \cdot A_{sep,t} \\ \frac{dA_{sep,t}}{dt} &= \gamma_{sep} \cdot B_t \end{aligned}$$

Lemma 1. *There exists a balanced-growth equilibrium in which the long-term growth rate of the stock of patents B_t and the growth rate of the stock of standards $A_{sep,t}$ converge to the growth rate of discovered technologies A_t irrespective of the initial values.*

Proof. The outline of the formal proof follows. The system of the two ODEs that describe the time-dynamics of patents and standards has a closed-form solution. The solution for both standards and patents has the common form $C_1 \cdot \exp^{\lambda_1 \cdot t} + C_2 \cdot \exp^{\lambda_2 \cdot t}$; C_1 and C_2 are constants that differ for patents and standards and depend on the initial values of patents and standards; λ_1 and λ_2 are the two eigenvalues of the matrix of coefficients A of the system of equations describing the dynamics of patents and standards:

$$A = \begin{pmatrix} \kappa \cdot H_A - N \cdot \gamma_{sep} & \kappa \cdot H_A \cdot N \\ \gamma_{sep} & 0 \end{pmatrix}$$

The eigenvalues of the matrix A are the roots of the equation:

$$(\kappa \cdot H_A - N \cdot \gamma_{sep} - \lambda)(-\lambda) - \gamma_{sep} \cdot \kappa \cdot H_A \cdot N = 0 \tag{14}$$

The equation (14) has two roots, one strictly negative and one strictly positive. This can be seen by plugging in $\lambda = 0$ in the left-hand side of the equation, which is a U-shaped parabola with a strictly negative intercept at $\lambda = 0$. In the long-term as $t \to +\infty$ all terms with a negative eigenvalue disappear from the solution form $C_1 \cdot \exp^{\lambda_1 \cdot t} + C_2 \cdot \exp^{\lambda_2 \cdot t}$ for both standards and patents. This leads to the ratios of standards and patents being asymptotically-constant, and thus the growth rates being identical in the long-term limit. □

When B_t grows at the same rate as A_t in a conjectured balanced growth equilibrium, the standard-essential patents $A_{sep,t}$ grow at that same rate as well. Thus the ratios B_t/A_t and $A_{sep,t}/A_t$ are constant in the balanced growth equilibrium. We solve for these ratios using the dynamics above:

$$\begin{aligned} B_t &= \zeta_B \cdot A_t \\ A_{sep,t} &= \frac{1}{N}(1-\zeta_B) \cdot A_t \\ &\quad \text{where: } \zeta_B = \frac{\kappa \cdot H_A}{\kappa \cdot H_A + N \cdot \gamma_{sep}} \end{aligned} \tag{15}$$

Proposition 1. *The endogenous growth rate g is the solution to the equation:*

$$\left(1 - \frac{g}{\kappa}\right) \cdot \frac{\rho + (1-\rho)(1+\epsilon_{sep})^{\frac{1}{\alpha}}}{\zeta_B + (1-\zeta_B)(1+\epsilon_{sep})^{\frac{1}{\alpha}}} = \frac{r}{\kappa} \cdot \frac{1}{(1-\alpha)} \tag{16}$$
$$\textit{where: } \rho = \frac{r}{r + N \cdot \gamma_{sep}}$$

Proof. Using (15), rewrite the final good production function in (3) as:

$$Y_t = (1-H_A)^{\alpha} A_t \left(\zeta_B + (1-\zeta_B)(1+\epsilon_{sep})^{\frac{1}{\alpha}}\right) \cdot \overline{x}_i^{1-\alpha}$$

In this formula everything is constant except the stock of discovered technologies A_t, which grows at an endogenous rate g. Thus the total output Y_t grows at g as well. Both patents and standard-essential patents grow at the same rate $\dot{B}_t/B_t = \dot{A}_{sep,t}/A_{sep,t}$ as the stock of discovered technologies $\kappa \cdot H_A$.

In equilibrium, the marginal product of human capital employed in the final good production sector is equal to the marginal product of human capital in the innovative patent-production sector. The equilibrium condition for the human capital allocation is:

$$\alpha \left(1 - H_A\right)^{\alpha-1} \left(\zeta_B + \left(1 - \zeta_B\right) \left(1 + \epsilon_{sep}\right)^{\frac{1}{\alpha}}\right) \cdot \overline{x}_i^{1-\alpha} \quad = \quad P_B \cdot \kappa \tag{17}$$

Note that to calculate the marginal product of human capital in the innovative patent-production sector we take the growth of newly discovered patents $\kappa \cdot A_t \cdot H_A$ rather than the growth of the patents without standards $\kappa \cdot B_t \cdot H_A$. The latter includes the effect of existing patents being eaten by newly set standards, while to measure productivity of human capital we count only newly discovered patents. Simplifying we get the endogenous growth rate g as the solution to the equation in the proposition. □

The last term in the equation in Proposition 1 captures the effect of standards and standard-essential patents on the endogenous growth rate g. Denote this term as:

$$G_{sep} = \frac{\rho + (1-\rho)\left(1 + \epsilon_{sep}\right)^{\frac{1}{\alpha}}}{\zeta_B + \left(1 - \zeta_B\right)\left(1 + \epsilon_{sep}\right)^{\frac{1}{\alpha}}} \tag{18}$$

where: $\rho = \dfrac{r}{r + N \cdot \gamma_{sep}}$

$\zeta_B = \dfrac{g}{g + N \cdot \gamma_{sep}}$

Equation (18) demonstrates that when $\epsilon_{sep} = 0$ there is no effect of standards on economic growth and $G_{sep} = 1$. When standards only reallocate market share among technologies, relative incentives of agents to engage in technology production are unchanged.

Either of the two conditions are required for standards to be growth-enhancing $G_{sep} > 1$:

1. Standards have a productivity-enhancing effect so that $\epsilon_{sep} > 0$ and the growth rate of the economy is higher than the cost of capital so that $g > r$.

2. Standards reduce marginal productivity of patents so that $\epsilon_{sep} < 0$ and the growth rate of the economy is lower than the cost of capital so that $g < r$.

Consider the first condition above. When growth rate of the economy g is relatively high, there are relatively more patents which are less productive than standards among the discovered technologies. This reduces incentives for the human capital to choose final good production sector, raises H_A in equilibrium, and increases the endogenous growth rate of the economy g. Alternatively, consider the second condition above. A relatively low growth rate g combined with the productivity-reducing effect of standards $\epsilon_{sep} < 0$ implies relatively fewer patents which are more productive than standards. This, as well, reduces incentives for the human capital to choose final good production sector.

As Romer [1990] for simplification we could use Ramsey consumers with CRRA utility function, risk aversion σ and inter-temporal discounting β. Then the interest rate on capital in the balanced growth equilibrium is $r = \sigma \cdot g + \beta$. When risk-aversion of consumers is sufficiently high, the risk-free rate is above the balanced growth rate g: $r > g$. When taken together with an assumption of a positive contribution of standardization to productivity $\epsilon_{sep} > 0$ our model predicts a surprising negative impact of standardization on long-term economic growth.

2.5 Extension with standards and M new patents

Recall that according to our original assumption, once a patent becomes a standard, the standardized technology substitutes for $N - 1$ individual rival technologies. However, a successful standardization of one technology may give birth to additional patentable ideas. To capture this technological spillover, we assume that with every new standard there are $M > 0$ new patents appearing and extending the stock of technologies in the economy. There are two changes to the equilibrium introduced by this extension: 1) the balanced growth will be affected by the additional dynamics of new patents, and 2) the patent value P_B will take into account the additional value created if we assume the new M patents belong to the owner of the standard.

Firstly, the new dynamics describing the balanced growth equilibrium are:

$$\frac{dA_{sep,t}}{dt} = \gamma_{sep} \cdot B_t \quad \text{and} \quad \frac{dB_t}{dt} = \kappa \cdot A_t \cdot H_A - (N - M) \cdot \gamma_{sep} \cdot B_t$$

Solving for the steady-state growth rates of patents and standards, we get:

$$\begin{aligned} B_t &= \zeta_B^M \cdot A_t \\ A_{sep,t} &= \frac{1}{N}\left(1 - \zeta_B^M\right) \cdot A_t \\ & \text{where: } \zeta_B^M > \frac{\kappa \cdot H_A}{\kappa \cdot H_A + N \cdot \gamma_{sep}}, \ \frac{d\zeta_B^M}{dM} > 0 \end{aligned}$$

The new patent value P_B is the same as before if the new patents do not belong to the owner of the standard. The modified equilibrium condition for the human capital allocation is:

$$\alpha \left(1 - H_A\right)^{\alpha - 1} \left(\zeta_B^M + \left(1 - \zeta_B^M\right)\left(1 + \epsilon_{sep}\right)^{\frac{1}{\alpha}}\right) \cdot \overline{x}_i^{1-\alpha} \quad = \quad P_B \cdot \kappa \tag{19}$$

Alternatively, if we assume the new M patents belong to the same person who owns the standard, the modified patent value P_B^M is:

$$\begin{aligned} P_B^M &= \delta_M \cdot P_B \\ & \text{where: } \delta_M = \frac{r(t) + N \cdot \gamma_{sep}}{r(t) + (N - M) \cdot \gamma_{sep}} \end{aligned}$$

To avoid bubbles in the patent valuation, we need to make an additional assumption that $M \leq N$. The modified equilibrium condition for the human capital allocation is:

$$\alpha \left(1 - H_A\right)^{\alpha - 1} \left(\zeta_B^M + \left(1 - \zeta_B^M\right)\left(1 + \epsilon_{sep}\right)^{\frac{1}{\alpha}}\right) \cdot \overline{x}_i^{1-\alpha} \quad = \quad \delta_M \cdot P_B \cdot \kappa \tag{20}$$

Since $\frac{d\zeta_B^M}{dM} > 0$ we know that the fraction of patents in the population will be higher, the higher is M. This would have a dampening effect on the incentive to produce final good if standards are productivity-enhancing $\epsilon_{sep} > 0$, and vice versa. In addition, if we assume the new M patents belong to the owner of the standard, the incentive to join the innovative sector strengthen. We conclude that for this when standards are productivity-enhancing $\epsilon_{sep} > 0$, the positive $M > 0$ increases the likelihood of the growth-enhancing outcome in equilibrium even when $r > g$.

3 Policy implications

3.1 Mandated compulsory licensing

Standard-essential patent, just like any patent, protects the monopolistic revenue π^M_{sep}, or at least some fraction of it, of the patent holder. The supra-competitive revenue remunerates the ex-ante efforts of generating innovation and obtaining the patent. In some fields, e.g., public provision of healthcare, the monopoly rents of patent holders may lead to an under-provision of an important service, and a market failure which justifies a governmental measure. One of the oldest policy have been compulsory licensing, in which the patent holder is obliged by the government to release the intellectual property to the end-users at some mandated price. More recently, under the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) governments can authorize various forms of compulsory licensing for its own purposes (Son [2019]).

Compulsory licenses on standard-essential patents are mandated, with fixed renumeration for patent holders, and recover some fraction $\delta < 1$ of the monopolistic revenue π^M_{sep}. In the context of our model, such regulation reduces the monopoly profit of the owner of the standardized technology so that equation (11) changes to:

$$\pi^M_{sep}(t) = \delta \cdot N \cdot (1 + \epsilon_{sep})^{\frac{1}{\alpha}} \pi^M(t) \tag{21}$$

In the extreme case of compulsory licensing for free, δ can be the probability of a favorable court ruling resulting in a royalty-free pricing and a loss of the monopoly power protection, as discussed in MacCarthy [2009]. The equilibrium effect of standards on the endogenous growth in equation (18) changes to:

$$\begin{aligned} G_{CL} &= \frac{\rho + \delta \cdot (1-\rho) \cdot (1+\epsilon_{sep})^{\frac{1}{\alpha}}}{\zeta_B + (1-\zeta_B) \cdot (1+\epsilon_{sep})^{\frac{1}{\alpha}}} < G_{sep} \qquad (22) \\ \text{where:} \quad & \rho = \frac{r}{r + N \cdot \gamma_{sep}} \\ & \zeta_B = \frac{g}{g + N \cdot \gamma_{sep}} \end{aligned}$$

When $\delta < 1$ our model predicts a reduction in the equilibrium long-term growth g according to the equation (17). When there is a positive contribution of standardization to productivity $\epsilon_{sep} > 0$ and $r > g$ we have:

$$G_{CL} < G_{sep} < 1$$

In case there is a negative contribution of standardization to productivity $\epsilon_{sep} < 0$ and $r > g$ there are two benchmark regions for the value of δ which are relevant for the prediction about the equilibrium long-term growth g:

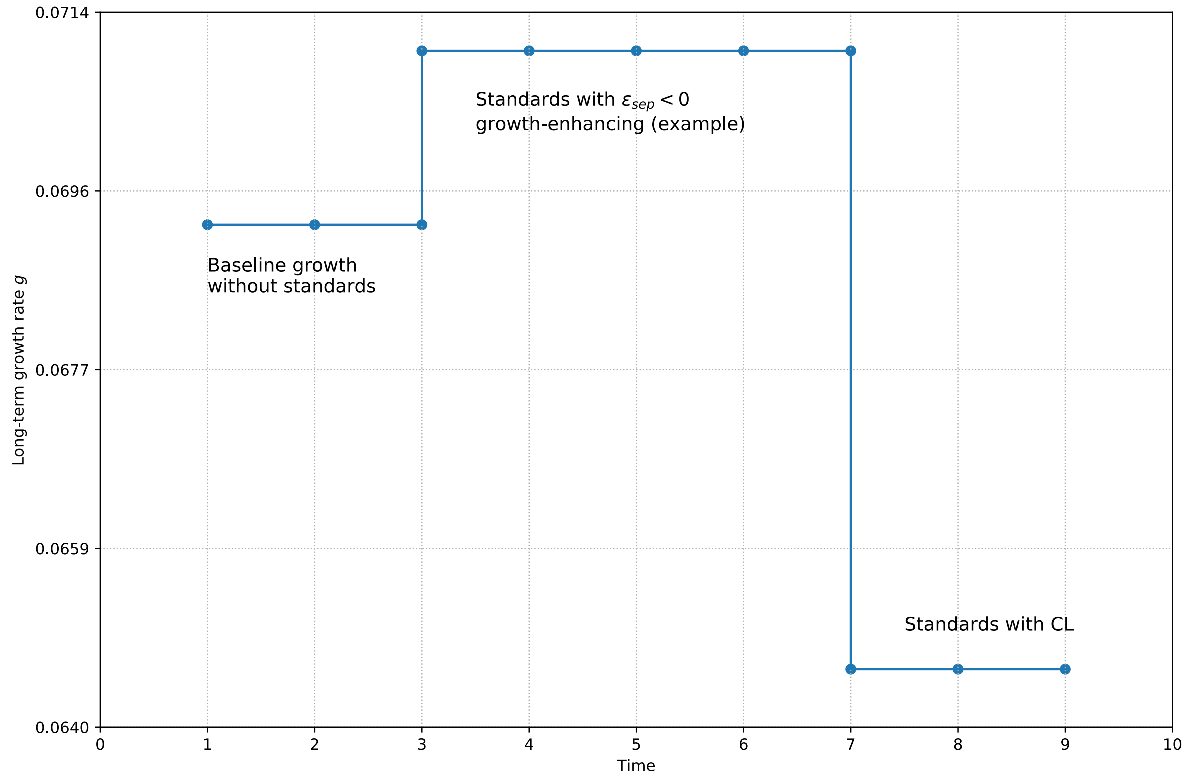
1. When $\delta > \overline{\delta} > (1+\epsilon_{sep})^{-\frac{1}{\alpha}}$ standards are still growth-enhancing, however the increase in growth due to introduction of standards is lower than when there is no regulation of mark-ups $\delta = 1$. The cutoff $\overline{\delta}$ is determined as the solution to the following equation:

$$\zeta_B + (1-\zeta_B)\cdot(1+\epsilon_{sep})^{\frac{1}{\alpha}} \quad = \quad \rho + \overline{\delta}\cdot(1-\rho)\cdot(1+\epsilon_{sep})^{\frac{1}{\alpha}} \tag{23}$$

2. When $\delta \leq (1+\epsilon_{sep})^{-\frac{1}{\alpha}}$ our model implies $\pi^{M}_{sep}(t) \leq N \cdot \pi^{M}(t)$ and standards reduce economic growth. Compulsory licensing cancels the effect of standards on the human capital incentives. In this setting standards have a negative contribution to productivity but the lower monopoly profits dominate and so incentives to innovate are lowered relative to incentive to produce final goods. The effect of standard-essential patents on the endogenous growth is $G_{CL} < 1$, which makes final good production more promising than innovation production for investment of human capital.

We conclude that compulsory licensing in our framework is growth-reducing. Compulsory licensing does offer a solution to the market failure, but at the cost of lower collaborative efforts today.

Figure 5: Growth with standards and compulsory licensing



The figure shows growth rates in the balanced growth equilibrium with a negative contribution of standardization to productivity $\epsilon_{sep} < 0$ and $r > g$. First three points on the graph correspond to growth rate in an equilibrium with no standards. Next five points correspond to growth rate in an equilibrium with standards and no regulation of mark-ups. The last three points correspond to growth rate in an equilibrium with standards and with price regulation in which $\delta = (1+\epsilon_{sep})^{-\frac{1}{\alpha}} < 1$. Compulsory licensing reduces the endogenous growth rate of the economy.

3.2 SEPs with voluntary FRAND

The baseline model predicts a drop in long-term growth following an introduction of mark-ups regulation, e.g., in the form compulsory licensing. An alternative pricing mechanism for essential patents is FRAND. Unlike compulsory licensing, FRAND is voluntary and could be renegotiated periodically. In this section we argue that FRAND can be growth-enhancing if standards with reasonable pricing give rise to M new patents, as in the section 2.5.

Unlike compulsory licensing, which is a "stick-measure" and has been documented to be often limited and sporadic (Son [2019]), the "carrot-measure" of FRAND pricing seem to be more promising in speeding up further development of the IP due to simplifying the "basics" of standard usage as an interface for everybody to use. Our model suggests it is important to complement mark-up regulation with promoting further innovation when addressing patent abuse.

Next, we discuss the patent pricing implications and how welfare can change in response to alternative pricing mechanism used to determine FRAND royalties. According to our model patent value, which takes into account the expected standardization in the future, is the key determinant of human capital incentives in equilibrium, as in the equation (17). Thus the actual pricing mechanisms behind FRAND have direct impact on the endogenous growth rate of the economy. There are several alternative pricing mechanisms, which differ in the timing of royalties negotiations and the set of participants in these negotiations. Those happening before the actual composition of the standard is set are called "ex ante" mechanisms, and are advocated in the analysis by Lerner and Tirole [2015] (as structured price commitments). Those happening after are called "ex post" and are much more common in practice, but supposedly less efficient due to potential hold up situations. In terms of the negotiations themselves, "ex ante" mechanisms may involve many potential patent holders and may be set up as an auction (Swanson and Baumol [2005]). The winning bidders in the auction will participate in the newly-formed standard. Farrell and Simcoe [2012] argue in favor of the collective negotiation of royalty rates which solves many practical difficulties arising from bilateral negotiation, including the hold up situations. Alternatively, in a bottom up approach, each patent holder will negotiate patent-specific royalties individually and independent of other patent holders with relevant patents (e.g. Contreras [2017]). The bottom up approach would be less preferable as it excludes direct participation of many other stakeholders and feedback effects among participating patents from the royalty negotiation process.

In the context of our model, a pricing mechanism which favors the patent owner and provides more bargaining power would imply a higher net present value of all future royalties collected P_B, however, it may make the standard composition sub-optimal and reduce the associated productive efficiency ϵ_{sep}. There is a trade-off between the better efficiency of the standard and the human capital incentives that affect long-term growth. Ideally, the pricing mechanism should strike well on both dimensions.

Illiquidity of patents and difficulty to resell ideas on a secondary market is another factor that hurts human capital incentives and lowers the right-hand side of the equation (17). Standard-essential patents may be made more liquid via the right market regulation and this effect will have an impact on the patent values through the discounting of the future expected rents. Thus we advocate for the stricter standard rules and making patents' secondary markets more liquid.

Moreover, there may be market-based enhancement of FRAND pricing, e.g., FRAND strips. FRAND strips could be designed as financial instruments to be offered by registered financial intermediaries. Each strip would trade license-related cash flows of individual patents in the standardized pool of IP. Importantly, trading FRAND strips would not result in surrendering of IP rights. FRAND strips may improve patent valuation via better market-based estimates of the expected profits π^M_{sep}, and enhance professional practices in portfolio patent management.

4 Conclusion

In this paper, we explore the role of standard-essential patents and technological standardization in the endogenous long-term economic growth setup. We show that the zero-sum redistribution of market share which occurs when the winning technological standard overtakes competing innovations is not enough by itself to raise incentives to innovate on an aggregate level. The innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Secondly, since the discovery of new technologies is typically slower than the discounting rate for the monopoly profits in equilibrium, standards with a positive contribution to productivity tend to be growth-reducing. The monopoly profits are discounted at a greater rate than the marginal productivity of the final good sector, and so relatively more benefits from standardization accrue to the less innovative sector of the economy, which on aggregate reduces marginal incentives to innovate. Then we show how positive spillovers of standards on innovation via the additional patents per standard may result in an additional endogenous economic growth despite the aforementioned discounting effect.

In our model mandated compulsory licensing of essential technologies has a negative impact on long-term growth. Compulsory licensing does offer a solution to the market failure, but at the cost of lower collaborative efforts today. Unlike compulsory licensing, which is a "stick-measure", the "carrot-measure" of FRAND pricing seem to be more promising in speeding up further development of the IP due to simplifying the "basics" of standard usage as an interface for everybody to use. Our model suggests it is important to complement mark-up regulation with promoting further innovation when addressing patent abuse.

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