Comparative statics

We first see how the equilibrium labor supply and relative wage change with quality.

Claim 2. *(i)* L_s^S*,* L_u^S *and* L_s^D *are increasing and* L_u^D *are decreasing in* Q*.*

(ii) Equilibrium relative wages and level of skilled labor are increasing in quality. That is, $\partial\xi^*(Q)/\partial Q > 0$ *and* $\partial L_s^*(Q)/\partial Q > 0$.

(See Figures 5 and 6. Proof is in the Appendix.) Higher quality makes consumption attractive for skilled workers and also increase proportion of all workers that consumer the high quality product. Thus both demand and supply of skilled labor is increasing in quality. The same effect increases the supply of unskilled workers and reduces demand for low quality good. The latter effect implies demand for unskilled workers decreases when quality improves.

Skilled labor supply is increasing in population, $\partial L_s^S/\partial N > 0$, from (9) and demand is also increasing in population, $\partial L_s^D/\partial N > 0$, from (7). (See proof of Claim 2 in the Appendix.) This implies

Claim 3. *Both equilibrium skilled and unskilled labor will increase when population increases,* $\partial L_s^*/\partial N > 0$ *and* $\partial L_u^*/\partial N > 0$.

Again, using the proof of Claim 2 in the Appendix, both demand and supply of skilled labor is also increasing in proportion of skilled consumers, $\partial L_s^S/\partial\theta > 0$, from (9) and $\partial L_s^D/\partial\theta > 0$, from (7).

Claim 4. *Equilibrium skilled labor and equilibrium relative wage are increasing in the proportion of skilled consumers,*$\partial L_s^*/\partial\theta > 0$ *and* $\partial\xi^*/\partial\theta > 0$.

Birthrate

Individual number of children are,

$$
\begin{aligned}
n_s^H(\xi) &= n_\sigma^*(w_s, w_s; Q) = \frac{\bar{\ell}}{Q^\sigma + 1}, \quad \sigma < \hat{\sigma}, \\
n_s^L(\xi) &= n_\sigma^*(w_u, w_s; 1) = \frac{\bar{\ell}}{\xi^{\sigma-1} + 1}, \quad \sigma > \hat{\sigma} \\
n_u^H(\xi) &= n_\sigma^*(w_s, w_u; Q) = \frac{\bar{\ell}}{Q^\sigma \xi^{1-\sigma} + 1}, \quad \sigma < \hat{\sigma}, \\
n_u^L(\xi) &= n_\sigma^*(w_u, w_u; 1) = \frac{\bar{\ell}}{2}, \quad \sigma > \hat{\sigma}.
\end{aligned}
$$

It is clear that for given wage level, those that consume high quality good devoted even more resources for consumption and thus reduce number of children when quality improves. Since the equilibrium relative wage in increasing in quality, we can say the following,

Claim 5. *(i) Skilled consumers have less children . That is ,* $n_s^H < n_u^H$ *for* $\sigma < \hat{\sigma}$ *and* $n_s^L < n_u^L$ *for* $\sigma > \hat{\sigma}$.

(ii) Skilled consumers have less children when quality of product improves. That is, $dn_s^H/dQ < 0$ *for* $\sigma < \hat{\sigma}$ *and* $dn_s^L < dQ$*¡0 for* $\sigma > \hat{\sigma}$.

(iii) Unskilled consumers that consume low quality product have the same number of children when quality improves. That is, $dn_u^L/dQ = 0$ *for* $\sigma > \hat{\sigma}$.

Although there is the income effect, the substitution effect dominates and skilled workers that consumer low quality reduce number of children. For unskilled consumers that bought high quality good, improvement makes consumption more attractive (reduce children) but their relative wage becomes lower and the substitution effect works in the opposite direction. The total effect is not clear.

Endogenous quality

Assume that level of quality is increasing in the size of the skilled labor. That is, $Q = Q_T(L_s)$ is an increasing function of Q. Subscript T refers to "technology" which is what this relationship reflects. We will denote the inverse relationship between the market equilibrium supply of skilled labor and quality of $L_s^*(Q)$ by $Q = Q_M(L_s)$, which is an increasing function from Claim 2. The equilibrium level of labor L_s^* and equilibrium level of quality, $Q^* = Q_M(L_s^*) = Q_T(L_s^*)$, is the intersection of the two curves.

When marginal increase in quality from labor is very large, then the equilibrium is unstable. Graphically, this would mean slope of Q_T is steeper than Q_M $(Q_T' > Q_M')$. This is the case around equilibrium E_1 in Figure 7. A perturbation away from E_1 results in either spiral increase in quality and skilled labor supply or decrease of quality and skilled labor supply. When technology is mature so that marginal quality improvement is very small, then equilibrium is stable $(Q_T' < Q_M')$. This is equilibrium E_2 in Figure 7. There may be multiple equilibria, some stable and others unstable. A slight perturbation from low quality with small skilled labor force will start a spiral of labor and quality improvement until E_2 is reached.

Now using Claim 3, we analyze the effect of declining population. The claim implies that the $Q_M(L_s)$ function will shift upward in the $L_s - Q$ space (Figure 8).

Claim 6. *(i) If the technology is in its infancy, then equilibrium quality and skilled labor supply increase when population declines. That is ,*

$$Q_T' > Q_M' \quad \Rightarrow \quad \frac{\partial Q^*}{\partial N} < 0, \quad \frac{\partial L_s^*}{\partial N} < 0.$$

(ii) If the technology is mature, then equilibrium quality and skilled labor supply decrease when the population decreases. That is ,

$$Q_T' < Q_M' \quad \Rightarrow \quad \frac{\partial Q^*}{\partial N} > 0, \quad \frac{\partial L_s^*}{\partial N} > 0.$$

When the technology is mature, then declining population results in "contraction" of the economy. That is, quality and supply of skilled labor are reduced. Claim 5 suggests that lower quality will increase the birthrate. Recall that all but unskilled consumers that consumed high quality product will increase birthrate when quality improves. This situation is consistent with cohort effect.

The situation is different when the technology still has not exhausted increasing marginal returns. The new equilibrium results in more skilled labor and higher quality. Products are more polarized, skilled labor has higher relative wages and work more. Utility is derived from more consumption and there is less children. The cohort effect does not hold because the economy adjusts to the lower level of population according to the available technology.

Now we consider the effect of more skilled workers, using Claim 4. The claim implies that the $Q_M(L_s)$ function will shift downward in the $L_s - Q$ space (Figure 9). Immediately we have the following,

Claim 7. *(i) If the technology is in its infancy, then equilibrium quality and skilled labor supply decrease when the proportion of skilled workers increase. That is ,*

$$Q'_T > Q'_M \quad \Rightarrow \quad \frac{\partial Q^*}{\partial \theta} < 0, \quad \frac{\partial L_s^*}{\partial \theta} < 0.$$

(ii) If the technology is mature, then equilibrium quality and skilled labor supply increase when the proportion of skilled workers increase. That is ,

$$Q'_T < Q'_M \quad \Rightarrow \quad \frac{\partial Q^*}{\partial \theta} > 0, \quad \frac{\partial L_s^*}{\partial \theta} > 0.$$

Equilibrium quality will decrease (increase) when technology is in its infancy (maturity). When proportion of skilled consumers increase, each skilled worker needs to supply less labor to maintain the same quality. When marginal quality from labor is very large, quality must be lower to accommodate it. Lower quality (and lower wage) likely to imply higher birthrate. Thus when technology is sufficiently productive, the increasing skilled workers will increase the birthrate. On the other hand when the marginal product of labor is low, then higher labor implies higher quality. This may reduce the birthrate.

Claims 6 and 7 suggest that increasing the proportion of skilled labor can be effective in reversing decline in birthrate whenever the cohort effect may not hod. This was the case when marginal return from increasing skilled labor is large. On the other hand, when the technology is mature, Esterlin Hypothesis is likely to hold and the same policy will prevent the feedback mechanism that otherwise will function.

4 Concluding Remarks

We have employed comparative statics of a general equilibrium framework to understand the long term (stationary equilibrium) effect of declining population on the economy, including labor supply and birthrate. We incorporated vertically differentiated goods in the general equilibrium model based on the observation of time series and cross sectional date of birthrate - female labor participation relationship.

Our analysis suggests that if the technology is productive enough, the economy will adjust to smaller population and the cohort effect does not reverse the trend of declining population. We also showed that increasing the proportion of skilled consumers (potential workers) can increase birthrate and reverse the trend precisely when the cohort effect does not hold. We note that the same relationship between population size and proportion of skilled consumers means that changing the proportion can prevent the natural feedback mechanism from functioning when it would have functioned.

The two situations are characterized by if the technology has high marginal return from skilled labor (infant) or if this has been exhausted (mature). The economy will correct itself when it is mature, where we also observed the equilibrium to be stable. Therefore, another possible policy is to let the technology mature quickly.

Besides extending the model to a dynamic framework, analysis of an economy such as Japan requires understanding the effect of international trade. Assuming Japan will export high quality products, trade should reduce the substitution effect of high quality product while maintaining or increasing the income effect. This suggests trade by itself could correct the bias towards consumption and less children. On the other hand, existing trade literature (Flam and Helpman (1987), Theonig and Verier (2003)) suggest that trade will lead to greater specialization, particularly in a dynamic framework. This is left for future research.

References

Acemoglu, Daron, 1998. "Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality," The Quarterly Journal of Economics, 113(4):1055-89

Atoh, Makoto, 2006. "International Comparison of Declining Birthrate and Policies in Japan, " in O.Saitao and N.Takayama eds., Economic Analysis of Declining Birthrate, Toyokeizai. (In Japanese, "Kokusaihikaku kara mita nihon-no shoshika to shosika taisaku")

Bloom, David E., David Canning, Gunther Fink, and Jocelyn E. Finlay, 2007. "Fertility, female labor force participation, and the demographic dividend," NBER Working Paper 13583.

Borarini, Romina and d'Ercole, Marco Mira, 2006. "Measures of Material Deprivation in OECD Countries," OECD Social, Employment and Migration Working Papers No.37.

Council for Gender Equality, Special Committee on the Declinign Birthrate and Gender-Equal Participation, 2006a. "International Comparison of the Social Environment regarding the Declining Birthrates and Gender-Equality - Summary Report," Cabinet Office, Government of Japan.

Council for Gender Equality, Special Committee on the Declinign Birthrate and Gender-Equal Participation, 2006b. "Domestic Comparison of the Social Environment regarding the Declining Birthrates and Gender-Equality - Summary Report," Cabinet Office, Government of Japan. (In Japanese, "Soshika to danjosanka ni kansuru shakaikankyo no kokunaibunseki hokokusho - gaiyou")

d'Addio ,Anna Cristina and Marco Mira d'Ercole, 2005. "Trends and Determinants of Fertility Rates in OECD Countries: The Role of Policies," OECD Social, Employment and Migration Working Paper No.27.

Da Rocha, Jose Maria and Juisa Fuster, 2006. "Why are Fertility Rates and Female Employment Ratios Positively Correlated Across OECD Countries", *International Economic Review* 47(4):1187-1222.

de Laat, Joost, and Sanz, Almudena Sevilla, 2006. "Wokring Women, Men's Home Time and Lowers-Low Fertility," ISER Working Paper 2006-23, Colchester: University of Essex.

Flam, Harry and Helpman, Elhanan, 1987. "Vertical Product Differentiation and North-South Trade," *American Economic Review* 77(5): 810–822.

Funke, Michael and Stuilik, Hoger, 2000. "On Endogenous Growth with Physical Capital, Human Capital and Product Variety," *European Economic Review* 44: 491–515.

Hasset, Michael, 2008. "Seeking a Life in Balance - Government's veiled Attempt to Address Labor Shortage Reeks and Comes at the Expense of Children," The Japan Times (Tuesday, January 1, 2008).

Helpman, Elhana, 1993. "Innovation, Imitation, adn intellectual Property Rights," *Econometrica* 61(6):1247–1280.

Kohler, Hans-Peter, Francesco C. Billari and Jose Antonio Ortega, 2006. "Low Fertility in Europe: Causes, Implications and Policy Options," in F.R.Harris ed., *The Baby Bust: Who will do the Work ? Who Will Pay the Taxes ?* Lanham,MD:Rowman & Littlefield Publishers:48-109.

Macunovich, Diane J., 1998. "Fertility and the Easterlin Hypothesis: An Assessment of the Literature," *Journal of Population Economics*, 11:1-59.

National Insitute of Population and Social Security Reserach, 2003. Cild Related Polices in Japan.

Robinson, Gwen, 2007. "Michelin Sprinkles Stars in Tokyo," Financial Times (November 20, 2007).

Sanderson, Warren C., 1976. "On Two Schools of the Economics of Fertility," *Population and Development Review* 2:469-478.

Sleebos, Jolle E., 2003. "Low Fertility Rates in OECD Countries: Facts and Policy Responses," OECD Social, Employment and Migration Working Paper No.15.

Suzuki, Toru, 2006. "Lower-Low Fertility and Geovernmental Actions in Japan," PIE Discusion Paper No. 294. Institute of Economic Research, Hitotsubashi University.

Thoenig, M., and Verdier, T., 2003. "A Theory of Defensive Skill-Biased Innovation and Globalization," *American Economic Review*, 93: 709-728.

Yomogida, M. and Reiko Aoki, 2005. "It Takes a Village - Network Effect of Child-rearing," PIE Discussion Paper No. 275, Institute of Economic Research, Hitotsubashi University.

Appendix

Optimization of $u(Qx, n)$

Denoting the Lagrange multiplier by λ, fist-order conditions are,

$$u_n f_x = \lambda p, \quad u_n f_\ell = \lambda w, \quad u_n g_x = \lambda p, \quad u_n g_\ell = \lambda w,$$

and the budget constraint. This implies

$$\frac{f_x}{f_\ell} = \frac{g_x}{g_\ell} = \frac{p}{w}.$$

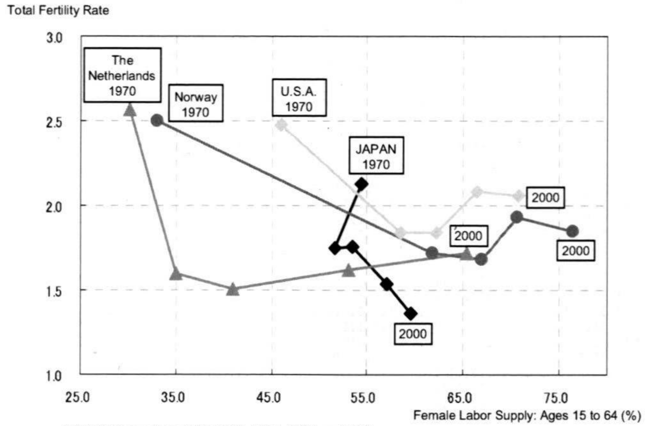
When w increases, ℓ_c and ℓ decrease while x and x_c increase.

Proof of Claim 2

The demand and supply functions, (7),(8), (9), and (10), can be rewritten as,

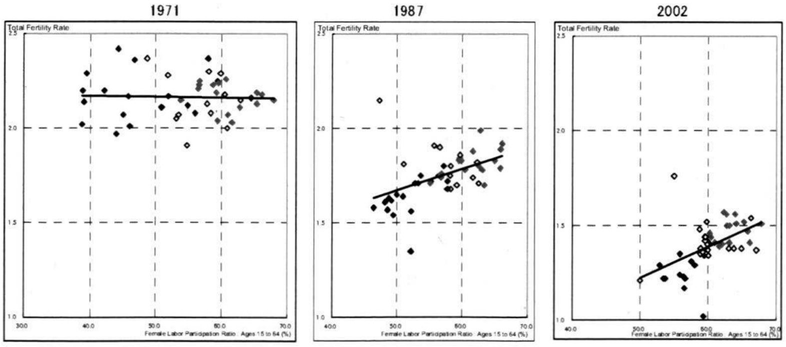
$$\begin{aligned}
L_s^S &= \theta N\bar{\ell}\int_1^\infty \frac{Q^\sigma}{Q^\sigma + \xi^{1-\sigma}} d\sigma + \theta N\bar{\ell}\int_{\hat{\sigma}}^\infty \left\{ \frac{Q^\sigma}{Q^\sigma + \xi^{1-\sigma}} - \frac{Q^\sigma}{Q^\sigma + 1} \right\} d\sigma \\
L_s^D &= \theta N\bar{\ell}\int_1^{\hat{\sigma}} \frac{Q^\sigma}{Q^\sigma + 1} d\sigma + (1-\theta) N\bar{\ell}\int_1^{\hat{\sigma}} \frac{Q^\sigma}{Q^\sigma \xi + \xi^\sigma} d\sigma \\
L_u^S &= (1-\theta) N\bar{\ell}\int_1^\infty \left\{ \frac{Q^\sigma \xi^{1-\sigma}}{Q^\sigma \xi^{1-\sigma} + 1} - \frac{1}{2} \right\} d\sigma + (1-\theta) N\bar{\ell}\int_1^\infty \frac{1}{2} d\sigma, \\
L_u^D &= (1-\theta) N\bar{\ell}\int_{\hat{\sigma}}^\infty \frac{1}{2} d\sigma + \theta N\bar{\ell}\int_{\hat{\sigma}}^\infty 1\xi^{-1} + \xi^{-\sigma} d\sigma.
\end{aligned}$$

The claim follows from noting that $\hat{\sigma}$ is decreasing in ξ and increasing in Q, and that $Q^\sigma \xi^{1-\sigma} > 1$ for $\sigma < \hat{\sigma}$.



NOTE) 5 time points: 1970, 1980, 1985, 1990, and 2000.

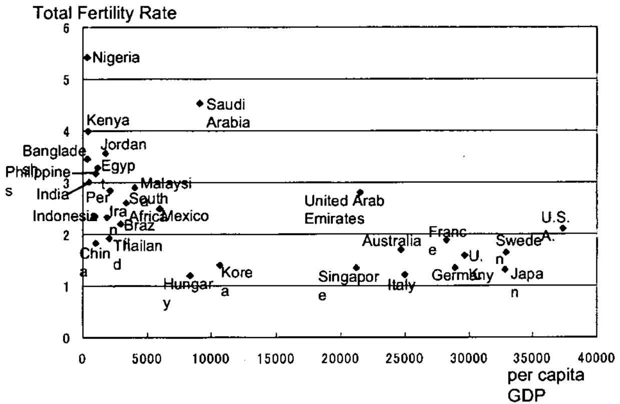
Figure 1: TFR and female labor supply 1970,80,85,90,2000
(Council for Gender Equality, Special Committee on the Declining Birthrate and Gender-Equal Participation, 2006a)



NOTE) Pink points are TYPE1(low declining rate in TFR and high level of TFR and female labor supply). Blue points are TYPE7(high declining rate in TFR and low level in TFR and female labor supply).

Sources) Ministry of Internal Affairs and Communications "Employment Status Survey," National Institute of Population and Social Security Research "Indicators of Fertility by Prefecture in 1970-1985," and Health, Labor and Welfare Ministry "Population Survey Report."

Figure 2: TFR and female labor participation ratio by prefecture in 1971, 1987, 2002
(Council for Gender Equality, Special Committee on the Decling Birthrate and Gender-Equal Participation, 2006b)



Source) United Nations Population Fund "State of World Population 2004" and IMF "World Economic Outlook Databases 2003."

Figure 3: TFR and Per Capita GDP
(Council for Gender Equality, Special Committee on the Declining Birthrate and Gender-Equal Participation, 2006a)

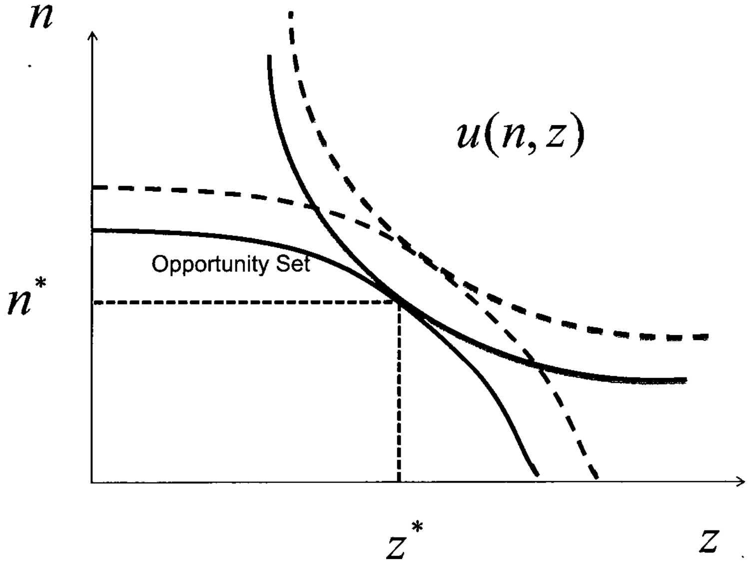


Figure 4: Optimization Problem

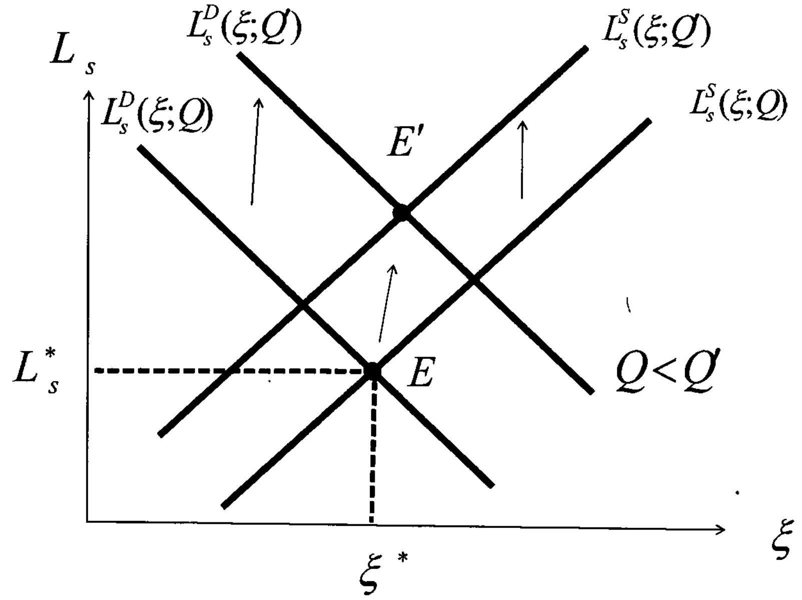


Figure 5: Skilled Labor Market

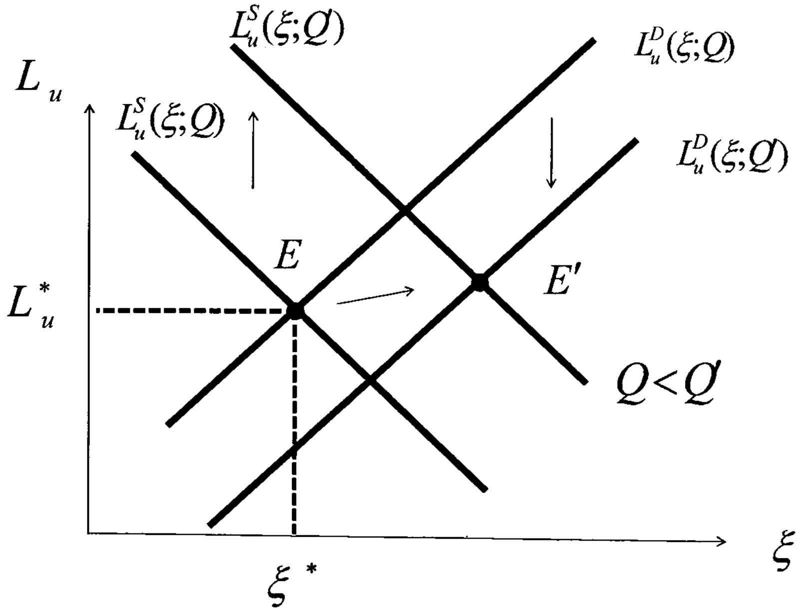


Figure 6: Unskilled Labor Market

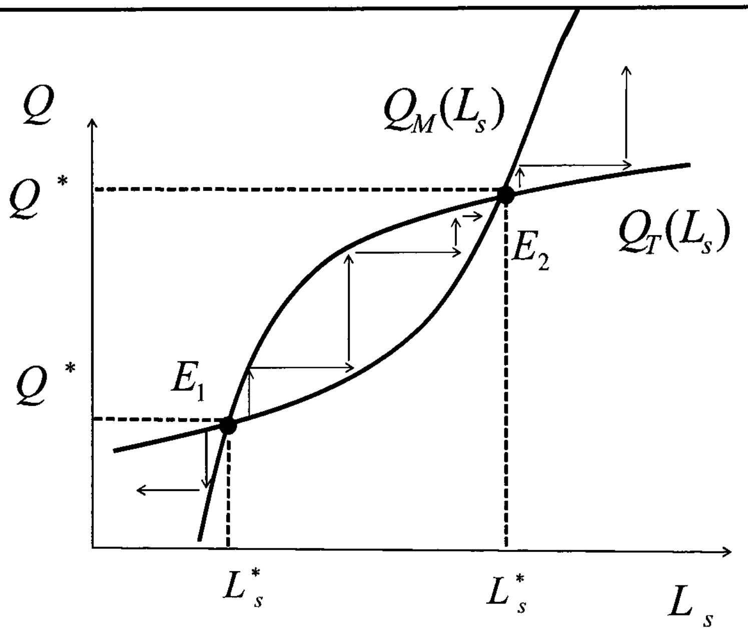


Figure 7: Equilibrium Quality and Skilled Labor

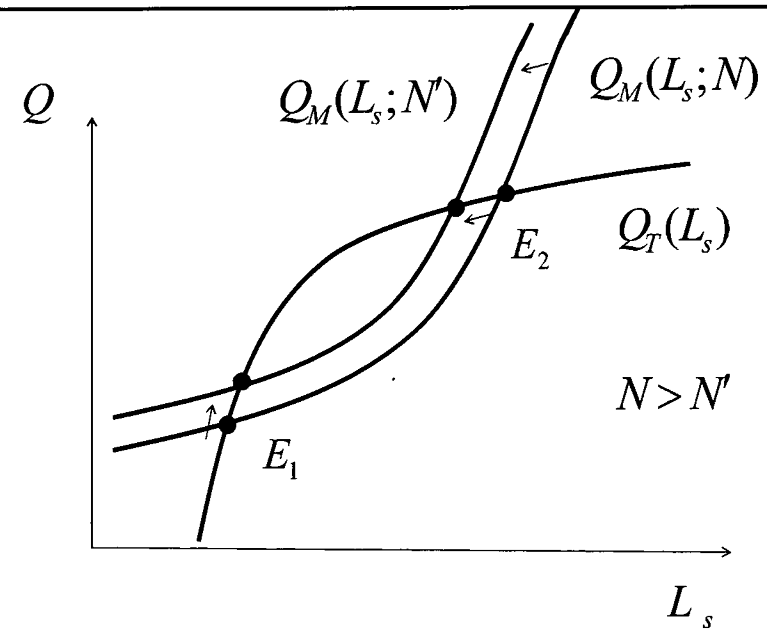


Figure 8: Declining Population

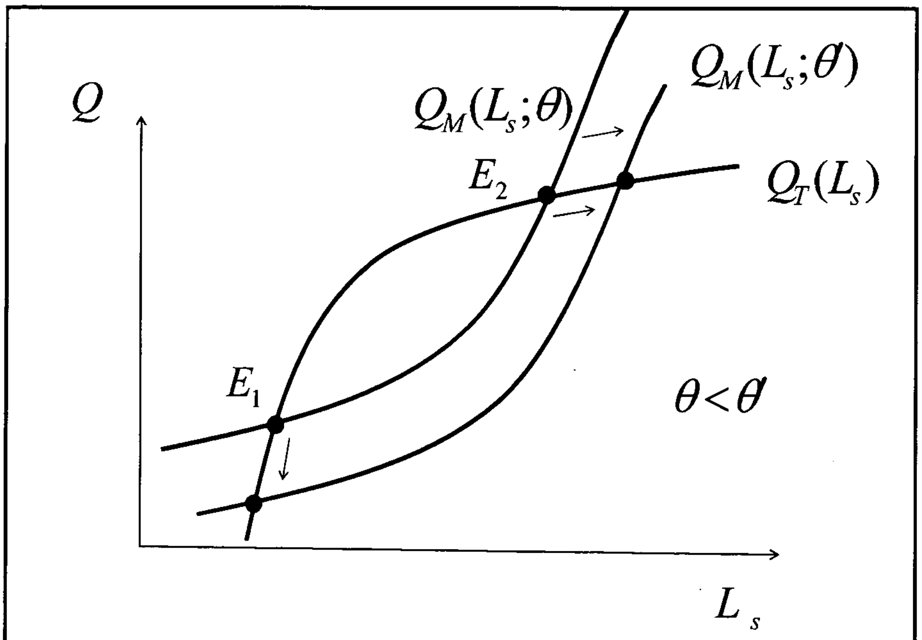


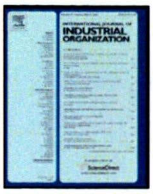
Figure 9: Larger Proportion of Skilled Labor

International Journal of Industrial Organization 27 (2009) 333–345

Contents lists available at ScienceDirect

International Journal of Industrial Organization

journal homepage: www.elsevier.com/locate/ijio



Pre-grant patent publication and cumulative innovation[☆]

Reiko Aoki [a,b], Yossi Spiegel [c,*]

[a] Center for Intergenrational Studies and Institute of Economic Research, Hitotsubashi University, Tokyo, Japan
[b] Department of Economics, University of Auckland, Private Bag 92109, Auckland, New Zealand
[c] Recanati Graduate School of Business Administration, Tel Aviv University, Ramat Aviv, Tel Aviv 69978, Israel

ARTICLE INFO

Article history:
Received 27 May 2007
Received in revised form 28 July 2008
Accepted 3 October 2008
Available online 15 October 2008

JEL classification:
O34
O31

Keywords:
R&D
Patents
Pre-grant patent publication
Patenting decision
Spillover
Consumer surplus
Welfare
Ex post licensing

ABSTRACT

We examine the implications of pre-grant publication (PP) of patent applications in the context of a cumulative innovation model. We show that PP leads to fewer applications and fewer inventions, but it may raise the probability that new technologies will reach the product market and thereby enhances consumer surplus and possibly total welfare as well.

1. Introduction

The two main objectives of patent systems are to encourage investments in R&D by granting inventors a temporary monopoly over the use of their inventions and to facilitate the dissemination of R&D knowledge. One aspect of patent systems that reflects the desire to balance these conflicting objectives is the requirement to publicly disclose pre-grant patent applications after 18 months from the date of application. This requirement, which is in place in practically every industrialized country (see Ragusa, 1992), implies that inventors may face the risk that their knowledge will be made public even if eventually their patent applications are rejected. Not surprisingly, opponents of this requirement argue that this risk may discourage innovations, especially by small independent inventors who lack the means to vigorously protect their intellectual property. A notable exception to the 18 months rule is the current U.S. patent system which allows applicants to keep their patent applications confidential until an actual patent is issued, provided that they do not seek patent protection in another country in which the 18 months rule applies.[1]

In this paper we examine the implications of pre-grant publication of patent applications in the context of a cumulative innovation model. In this model, two firms engage in an R&D process aimed at developing a new commercial technology. Our analysis begins when one of the two firms has managed to accumulate enough interim R&D knowledge to file for a patent.[2] We then examine what are the effects of pre-grant patent publication (PP) on the incentives of the leading firm to apply for a patent on its interim R&D knowledge, and on the R&D investments of the two firms which determine their likelihood to successfully develop the new commercial technology.

In principle, pre-grant patent publication (PP) may have two main effects: first, it creates a technical spillover because the lagging firm gets access to the leading firm's interim R&D knowledge when the

---

[☆] An earlier version of this paper was circulated under the title "Public Disclosure of Patent Applications, R&D, and Welfare" (Foerder Institute Working Paper No. 30-98). We thank two anonymous referees for their comments on the current version, and Masayoshi Omachi for helpful discussions on some of the institutional details and facts.

[*] Corresponding author.
E-mail addresses: aokirei@ier.hit-u.ac.jp (R. Aoki), spiegel@post.tau.ac.il (Y. Spiegel).
URL: http://www.tau.ac.il/~spiegel (Y. Spiegel).

[1] The Patent Reform Act of 2007 (H.R. 1908 and S.1145 of the 110th Congress) proposes to eliminate the exemption. Until the passage of the American Inventors Protection Act (AIPA) in 1999, all patent applications in the U.S. were kept confidential until a patent was actually granted. Since 1999, approximately 10% of all applicants opt-out of publication (FTC, 2005, p. 11).

[2] For instance, in the context of biotechnology, the interim R&D knowledge could represent a research tool like a cell line, chemical reagent, or antibody which is used in research but need not have an independent commercial value.

0167-7187/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijindorg.2008.10.002

Fig. 1. The sequence of events.

patent application is made public even if the application is eventually rejected. Second, PP may credibly reveal to the lagging firm that the leading firm is indeed leading and may also affect its beliefs about the extent of this lead. In this paper we focus on the first, technological spillover, effect of PP. This effect figures prominently in the public debate in the U.S. about PP.

We show that the implications of PP depend on the strength of patent protection, which depends in our model on two factors: (i) the likelihood that the patent office will grant the leading firm a patent on its interim R&D knowledge, and (ii) the likelihood that the patent will be upheld in court. PP matters however only if patent protection is strong or intermediate because under weak protection, the leading firm does not file for a patent even when patent applications are kept confidential. On the other hand, when patent protection is strong, the leading firm files for a patent even when a PP is in place. But since PP creates a technological spillover, it induces the leading firm to cut its R&D investment while inducing the lagging firm to invest more. When the cost of R&D is quadratic, PP raises the overall likelihood that the new technology will reach the product market, and hence it benefits consumers. If in addition the marginal cost of R&D is sufficiently large, then PP also raises social welfare (measured as the sum of the expected consumers' surplus and expected profits). On the other hand, PP hurts the leading firm and hence, weakens its incentives to accumulate interim R&D knowledge in the first place.

Things are more subtle when patent protection is intermediate. Now the leading firm files for a patent when patent applications are confidential but not when they are made public. Moreover, the effect of PP on the R&D investments depends on the likelihood that patents will be upheld in court: when this likelihood is large, PP induces the leading firm to cut its R&D investment while inducing the lagging firm to invest more. When the likelihood that patents will be upheld in court is small, PP has an ambiguous effect on the R&D investments. Nonetheless, when the cost of R&D is quadratic, PP still benefits consumers regardless of the likelihood that patents will be upheld in court. And, when the marginal cost of R&D is sufficiently large, PP enhances social welfare if patents are likely to be upheld in court, but it decreases social welfare otherwise.

The economic literature has already studied various aspects of patent laws, including the optimal length and breadth of patents (e.g., Nordhaus, 1969; Gilbert and Shapiro, 1990; Klemperer, 1990; Gallini, 1992; Chang, 1995; Green and Scotchmer, 1995; Matutes et al., 1996; O'Donoghue et al., 1998), priority rules such as "first to file" versus "first to invent" (e.g., Scotchmer and Green, 1990), novelty requirements (e.g., Scotchmer, 1996; Eswaran and Gallini, 1996; O'Donoghue, 1998), the optimal renewal of patents (Cornelli and Schankerman, 1999), and the optimal length of protection given to the first firm to discover interim R&D knowledge (Bloch and Markowitz, 1996). However, pre-grant patent publication has received very little attention in the economic literature. Given the continuing debate in the U.S. about the 18 months rule, it seems that a formal economic analysis of this issue is badly needed.

We are aware of only two papers that examine the implication of PP. Aoki and Prusa (1996) assume that PP reveals information about the quality choice of the first filer. They show that this information allows firms to coordinate their R&D investments and achieve a more collusive outcome. Unlike the current paper though, the decision to patent is not endogenous, filing for a patent does not create a technological spillover, and patenting does not allow the first filer to exclude its rival from the product market. Johnson and Popp (2003) examine citation analysis on all U.S. domestic patents from 1976 to 1996 and find that more "significant" patents (those that are subsequently cited more often) tend to take longer through the application process and hence are more likely to be affected by PP. Moreover, their analysis suggests that earlier disclosure should lead to faster diffusion of R&D knowledge. While faster diffusion benefits future inventors, it hurts the filing inventors and may therefore make them more reluctant to file for patents.

The rest of the paper is organized as follows: in Section 2 we describe the model and in Sections 3 and 4 we study the equilibrium under the PP and CF systems. In Section 5 we compare the two filing systems in terms of the equilibrium patenting and investment behavior of the two firms and use the results to examine the implications of PP for consumers' surplus and social welfare. We then consider the possibility that the two firms will engage in licensing in Section 6, and in Section 7 we examine the implications of PP for the firms' incentives to accumulate interim R&D knowledge. We conclude in Section 8. All proofs are in the Appendix A.

2. The model

Two firms engage in an R&D process aimed at developing a new commercial technology. Suppose that the R&D process has reached a critical point where one of the two firms, firm 1, has accumulated enough interim knowledge to apply for a patent. This knowledge represents, say, a research tool or some basic technology which lowers the cost of R&D in the rest of the R&D process. Although the patent (if granted) covers only the interim knowledge of firm 1, it nonetheless allows it to sue firm 2 for patent infringement if firm 2 eventually manages to develop the new technology. In most of the paper, we shall assume that when firm 1 holds a patent, it always sues firm 2 when the latter develops the new technology; this assumption can be justified on the grounds that firm 1 wishes to develop reputation for vigorously protecting its intellectual property. In Section 6 we shall relax this assumption and consider ex post licensing which takes place when firm 1 fails to develop the new technology while firm 2 succeeds.[3] The cost of applying for a patent is that some of firm 1's interim knowledge is spilled over to firm 2 either through the patent application (if it is made public), or through an actual patent (if and when it is granted).[4]

Given firm 1's patenting decision, but before the patent office makes a decision, the two firms decide how much to invest in the rest of the R&D process. The investment of each firm determines its eventual probability of success. We assume that the outcome of the R&D process is binary: each firm either succeeds to develop the new technology or it fails and develops nothing. Once the R&D process ends, the two firms compete in the product market. The sequence of events is summarized in Fig. 1.

---

[3] Another possibility is that firm 1 will license its interim R&D knowledge to firm 2 ex ante, before the outcome of the R&D process is decided. For analysis of this kind of licensing, see Spiegel (2008).

[4] This tradeoff is reminiscent of the tradeoff in Horstman et al. (1985), although the technological spillover in their model arises because patenting reveals to the lagging firm how profitable it would be to imitate the leading firm. For a related tradeoff, see Erkal (2005).

2.1. The filing system

We consider two filing systems: under a pre-grant patent publication system (PP system), the contents of patent applications are automatically published after a certain period of time from the application date (typically 18 months). Under a confidential filing system (CF system), patent applications are kept confidential until a patent is granted; if an application is rejected, then no information is revealed.

In practice, patent protection is imperfect both because patent applications are sometimes rejected by the patent office if they are not deemed sufficiently novel, useful, or non-obvious, and because actual patents are not always upheld in court.[5] We capture these imperfections by assuming that firm 1's patent application is approved with probability $\theta \in [0,1]$, and if firm 1 sues firm 2 for patent infringement, then it wins in court with probability $\gamma \in [0,1]$.[6] Throughout we treat θ and γ as exogenous parameters.[7]

2.2. The cost of R&D

Given firm 1's filing decision, but before the patent office decides whether to grant firm 1 a patent, firms 1 and 2 simultaneously choose how much to invest in the rest of the R&D process.[8] For analytical convenience, we shall assume that the two firms directly choose their probabilities of success, q^1 and q^2, and these choices determine their respective R&D cost functions, which are given by $C(q^1)$ and $\beta C(q^2)$, where $\beta > 1$ because firm 2 does not have full access to firm 1's interim knowledge. We assume that $C(\cdot)$ is twice continuously differentiable, increasing, and strictly convex, with $C'(0) = 0$.[9] The value of β depends on the degree of technological spillover which in turn depends on whether firm 1 applies for a patent and on which filing system is in place. We assume that the value of β is lowest and equals β_L if firm 1 applies for a patent and a PP system is in place; in that case, firm 2 gets access to firm 1's interim knowledge through firm 1's patent application. The value of β is intermediate and equals β_M if a patent is granted and a CF system is in place; firm 2 then gets access to firm 1's only through the patent itself. Finally, the value of β is largest and equals β_H if either firm 1 does not apply for a patent, or if it does but its patent application is rejected and a CF system is in place. In both cases, there is no technological spillover.[10]

We assume that the fact that firm 1's cost of R&D is lower is common knowledge. As mentioned in the Introduction, without this assumption, PP would not only create a technological spillover, but would also reveal to firm 2 that firm 1's cost is $C(q)$ and not higher. This will affect firm 1's incentive to file for a patent under the PP system. In the current paper, however, we wish to focus on the technological spillover effect and hence eliminate the effect of PP on firm 2's beliefs by adopting the common knowledge assumption.[11]

2.3. Competition in the product market

Once the R&D process ends, the two firms compete in the product market. Instead of assuming a specific type of product market competition, we simply assume that if only one firm succeeds to develop the new technology (this firm can be either firm 1 or 2), then the net present value of its profits is π_{yn} and the net present value of its rival's profits is π_{ny}. If both firms succeed to develop the new technology, then the net present value of their profits is π_{yy}, and if neither firm succeeds, the net present value of their profits is π_{nn}.[12] Throughout, we make the following assumptions:

A1. $\pi_{yn} > \pi_{yy} \geq \pi_{nn} \geq \pi_{ny}$.

A2. $C'(1) > \max\{\pi_{yn} - \pi_{nn}, \pi_{yy} - \pi_{ny}\}$, and $C''(q) > \Pi$, where $\Pi \equiv \pi_{yn} + \pi_{ny} - \pi_{yy} - \pi_{nn}$ for all $q \in [0,1]$.

Assumption A1 holds whenever the products of firms 1 and 2 are substitutes. Assumption A2 ensures that the best-response functions of firms 1 and 2 are well behaved. Moreover, the first part of Assumption A2 ensures that it is too costly to invest up to the point where developing the new technology becomes a sure thing, irrespective of whether the rival firm does or does not develop the new technology.

3. The pre-grant patent publication (PP) system

When firm 1 files for a patent under the PP system, it can prevent firm 2 from bringing the new technology to the product market (if firm 2 develops it) with probability $\gamma\theta$, which is the probability that a patent is granted and is upheld in court. Hence, $\gamma\theta$ reflects the effective patent protection that firm 1 enjoys. Recalling that the success probabilities of firms 1 and 2 are q^1 and q^2, the expected payoffs of the two firms are

$$\begin{aligned}\pi^1\left(q^1,q^2|F\right) = {} & q^1\left[q^2(1-\gamma\theta)\pi_{yy} + \left(1-q^2(1-\gamma\theta)\right)\pi_{yn}\right] \\ & + \left(1-q^1\right)\left[q^2(1-\gamma\theta)\pi_{ny} + \left(1-q^2(1-\gamma\theta)\right)\pi_{nn}\right] - C\left(q^1\right).\end{aligned} \tag{1}$$

and

$$\begin{aligned}\pi^2\left(q^1,q^2|F\right) = {} & q^1\left[q^2(1-\gamma\theta)\pi_{yy} + \left(1-q^2(1-\gamma\theta)\right)\pi_{ny}\right] \\ & + \left(1-q^1\right)\left[q^2(1-\gamma\theta)\pi_{yn} + \left(1-q^2(1-\gamma\theta)\right)\pi_{nn}\right] - \beta_L C\left(q^2\right).\end{aligned} \tag{2}$$

The first bracketed term in Eq. (1) is firm 1's payoff when it succeeds to develop the new technology. With probability $q^2(1-\gamma\theta)$, firm 2 also succeeds and is free to use the new technology in the

---

[5] In 2003, the grant rates were 59.9% at the EPO, 49.9% at the JPO, and 64% at the USPTO (USPTO, 2004, Table 4). Allison and Lemley (1998) find that out of the 300 final patent validity decisions by U.S. courts during the period 1989–1996, only 162 patents (54%) were held valid. In Japan, the original patent was upheld in only 23 out of the 51 patent infringement suits studied between April 2000 and January 2003 (45.1%) (Material prepared for 4th meeting of Subcommittee on Intellectual Property Disputes, Committee for Legal System Reform Headquarters for Promotion of Judicial Reform, Prime Minister's Office (January 31, 2003)).

[6] The assumption that patent protection is imperfect has also been made elsewhere. Meurer (1989), Anton and Yao (2003, 2004), and Choi (1998) assume that patents can be challenged in court and may be ruled as invalid, but the possibility that patent applications may be rejected plays no role in these papers. Kabla (1996) assumes that patent applications may be rejected, but does not consider the possibility that patents may not be upheld in court. Waterson (1990) and Crampes and Langinier (2002) assume that suing for patent infringement is costly so patentholders do not always sue imitators. Finally, Crampes and Langinier (1998) show that under certain conditions, firms may choose not to renew their patents in order to conceal favorable market information from potential entrants.

[7] According to the enablement doctrine of patent law, "claims ought to be bounded to a significant degree by what the disclosure enables, over and beyond prior art" (Merges and Nelson, 1994, p.10). Thus, in a more general model where firm 1 can choose the scope of its disclosure, the likelihood that a court will uphold firm 1's patent would be an endogenous variable.

[8] This timing reflects the fact that patent examination is typically a lengthy process: pendency time at USPTO was 26.7 months in 2003. Pendency times at EPO and JPO were 37.7 and 31.1 months respectively. (See USPTO, 2004 for details, including definition.)

[9] Given that $C(\cdot)$ is increasing, there is a 1.1 relationship between the probability of success and the cost of achieving it so it is equally possible to assume that the two firms choose how much to spend on R&D and these choices determine their respective probabilities of success.

[10] The assumption that $\beta_H > \beta_M > \beta_L$ is consistent with Mansfield et al. (1981) who estimate that the average ratio between the cost of imitating an existing technology ($\beta_L C(q)$ or $\beta_M C(q)$ in our model) and the cost of innovating it from scratch ($\beta_H C(q)$ in our model) is 0.65.

[11] For papers that study the effect of voluntary disclosure of R&D knowledge on the beliefs of rival firms, see for example Lichtman et al. (2000), Gordon (2004), Jansen (2008), and Gill (2008).

[12] To economize on notation we assume that the product market profits are symmetric: π_{yy}, π_{yn}, π_{ny}, and π_{nn} are the same for both firms. This assumption is not important however and none of our results depends on it.

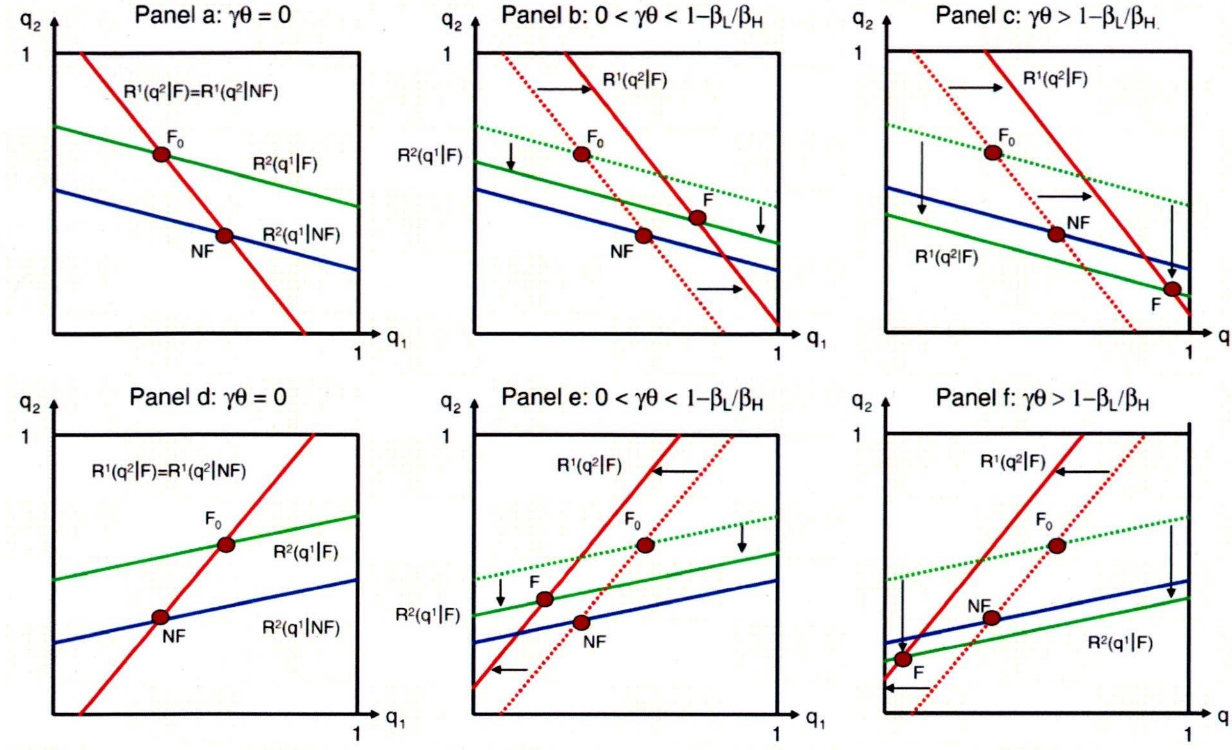


Fig. 2. The Nash equilibrium in the filling and the no-filling subgames and how it changes with increases in $\gamma\theta$.

product market, so firm 1's payoff is π_{yy}; with probability $1-q^2(1-\gamma\theta)$, firm 2 either fails or else it succeeds but it is prevented from using the new technology, so firm 1's payoff is π_{yn}. The second bracketed term in Eq. (1) represents the corresponding expressions when firm 1 fails to develop the new technology. The interpretation of Eq. (2) is similar. Firm 2's cost is $\beta_L C(q^2)$ because firm 2 gets access to firm 1's interim knowledge through firm 1's patent application.

Absent filing, firm 1 cannot prevent firm 2 from using the new technology if firm 2 develops it. Hence, the expected payoffs of the two firms are

$$\pi^1\left(q^1,q^2\,|\,NF\right) = q^1\left[q^2\pi_{yy} + \left(1-q^2\right)\pi_{yn}\right] + \left(1-q^1\right)\left[q^2\pi_{ny} + \left(1-q^2\right)\pi_{nn}\right] - C\left(q^1\right), \tag{3}$$

and

$$\pi^2\left(q^1,q^2\,|\,NF\right) = q^1\left[q^2\pi_{yy} + \left(1-q^2\right)\pi_{ny}\right] + \left(1-q^1\right)\left[q^2\pi_{yn} + \left(1-q^2\right)\pi_{nn}\right] - \beta_H C\left(q^2\right). \tag{4}$$

These expressions differ from the corresponding expressions in the filing subgame in two ways: first, the probability that firm 2 uses the new technology in the product market is now q^2 instead of $q^2(1-\gamma\theta)$. Second, absent filing, there is no technological spillover, so firm 2's cost of R&D is $\beta_H C(q^2)$ instead of $\beta_L C(q^2)$, where $\beta_H > \beta_L$.

Let $R^1(q^2|F)$ and $R^2(q^1|F)$ be the best-response functions in the filing subgame; these functions are defined implicitly by $\frac{\partial\pi^1(q^1,q^2|F)}{\partial q^1} = 0$ and $\frac{\partial\pi^2(q^1,q^2|F)}{\partial q^2} = 0$. Similarly, the best-response functions in the no-filing subgame, $R^1(q^2|NF)$ and $R^2(q^1|NF)$, are defined implicitly by $\frac{\partial\pi^1(q^1,q^2|NF)}{\partial q^1} = 0$ and $\frac{\partial\pi^2(q^1,q^2|NF)}{\partial q^2} = 0$. Assumptions A1 and A2 ensure that the best-response functions in both subgames are well-defined and single-valued. The best-response functions are downward sloping in the (q^1, q^2) space (q^1 and q^2 are strategic substitutes) if $\Pi \equiv \pi_{yn} + \pi_{ny} - \pi_{yy} - \pi_{nn} > 0$ and are upward sloping (q^1 and q^2 are strategic complements) if $\Pi < 0$. To interpret Π, note that it can be written as $(\pi_{yn}-\pi_{nn})-(\pi_{yy}-\pi_{ny})$, where $\pi_{yn}-\pi_{nn}$ is the extra profits generated by the new technology when the rival fails to develop it, and $\pi_{yy}-\pi_{ny}$ is the corresponding extra profit when the rival succeeds. When $\Pi > 0$, having the new technology is more profitable when the rival does not have it and conversely when $\Pi < 0$.

The Nash equilibrium in the filing subgame, (q_F^1, q_F^2), is determined by the intersection of $R^1(q^2|F)$ and $R^2(q^1|F)$, while the Nash equilibrium in the no-filing subgame, (q_{NF}^1, q_{NF}^2), is determined by the intersection of $R^1(q^2|NF)$ and $R^2(q^1|NF)$. Assumptions A1 and A2 ensure that (q_F^1, q_F^2) and (q_{NF}^1, q_{NF}^2) are unique and lie inside the unit square (recall that q^1 and q^2 are probabilities and hence must be between 0 and 1).[13]

To see how the effective patent protection, $\gamma\theta$, affects the R&D investments, note that $\frac{\partial^2\pi^1(q^1,q^2|F)}{\partial q^1\partial(\gamma\theta)} = q^2\Pi$ and $\frac{\partial^2\pi^2(q^1,q^2|F)}{\partial q^2\partial(\gamma\theta)} = -\left[q^1(\pi_{yy}-\pi_{ny}) + (1-q^1)(\pi_{yn}-\pi_{nn})\right]$. Hence, when $\gamma\theta$ increases, $R^1(q^2|F)$ shifts outward if $\Pi > 0$ (q^1 and q^2 are strategic substitutes) and inwards if $\Pi < 0$ (q^1 and q^2 are strategic complements); by contrast, Assumption A1 ensures that $R^2(q^1|F)$ always shifts inward. As a result, q_F^1 increases with $\gamma\theta$ if $\Pi > 0$ and decreases with $\gamma\theta$ if $\Pi < 0$, while q_F^2 always decreases with $\gamma\theta$ irrespective of Π. Intuitively, as $\gamma\theta$ increases, firm 2 is less likely to bring the new technology to the product market and hence its marginal benefit from R&D falls; as a result firm 2 invests less. As for firm 1, note that its marginal benefit from R&D is a weighted average of $\pi_{yn}-\pi_{nn}$ and $\pi_{yy}-\pi_{ny}$. When $\gamma\theta$ increases, firm 1 is more likely to block firm 2 from using the new technology and hence its extra profits is more likely to be $\pi_{yn}-\pi_{nn}$ rather than $\pi_{yy}-\pi_{ny}$. This in turn boosts firm 1's incentive to invest if and only if $\pi_{yn}-\pi_{nn} > \pi_{yy}-\pi_{ny}$, i.e., if and only if $\Pi > 0$.

Fig. 2 illustrates the equilibria in the filing and the no-filing subgames and shows how they are affected by $\gamma\theta$.[14] Panels a–c show

---

[13] The proof appears in a technical appendix which is available at www.tau.ac.il/~spiegel.

[14] For simplicity, we draw the best-response functions as straight lines even though in general this need not be the case. This however does not affect any of our conclusions.

the case where $\Pi>0$ (q^1 and q^2 are strategic substitutes) and Panels d–f show the case where $\Pi<0$ (q^1 and q^2 are strategic complements). Panels a and d show that in the extreme case where $\gamma\theta=0$ (firm 1 gets no patent protection), $R^1(q^2|F)=R^1(q^2|NF)$. On the other hand, given that $\beta_L>\beta_H$, the marginal cost of q^2 is lower in the filing subgame, so $R^2(q^1|F)>R^2(q^1|NF)$. Hence, the equilibrium point in the filing subgame, F_0, lies northwest of the equilibrium point in the no-filing subgame, NF, if $\Pi>0$ and northeast of NF if $\Pi<0$. As $\gamma\theta$ increases, $R^1(q^2|F)$ shifts to the right when $\Pi>0$ and to the left when $\Pi<0$. By contrast, $R^2(q^1|F)$ shifts down irrespective of Π. Panels b and e show that as a result, the equilibrium point in the filing subgame shifts southeast (southwest) from F_0 to F if $\Pi>0$ ($\Pi<0$). Panels c and f show that when $\gamma\theta\geq 1-\beta_L/\beta_H$, $R^2(q^1|F)$ drops below $R^2(q^1|NF)$, so F is attained southeast (southwest) of NF if $\Pi>0$ ($\Pi<0$). Notice that an increase in $\gamma\theta$ always leads to decrease in q_F^2, but leads to an increase in q_F^1 if $\Pi>0$ and a decrease in q_F^1 if $\Pi<0$.

Next let $\pi_F^1\equiv\pi^1(q_F^1, q_F^2|F)$ and $\pi_{NF}^1\equiv\pi^1(q_{NF}^1, q_{NF}^2|NF)$ be the Nash equilibrium payoffs of firm 1 in the filing and in the no-filing subgames, and define π_F^2 and π_{NF}^2 similarly. Then, we can prove the following result (the proof, along with all other proofs, is in the Appendix A):

Proposition 1. *(Firm 1's filing decision under the PP system.) There exists a unique critical value of $\gamma\theta$, denoted $\widehat{\gamma\theta}$,* where $\widehat{\gamma\theta}\in$ $(0,(1-\beta_L/\beta_H))$, *such that $\pi_F^1\gtreqless\pi_{NF}^1$ as $\gamma\theta\gtreqless\widehat{\gamma\theta}$.*

Proposition 1 implies that firm 1 files for a patent under the PP system if and only if the effective patent protection, $\gamma\theta$, exceeds a threshold level, $\widehat{\gamma\theta}$. Intuitively, firm 1 does not file for a patent when $\gamma\theta$ is small because then it loses some of its technological advantage, without enjoying much protection against imitation. As $\gamma\theta$ increases, patents receive stronger protection so filing becomes more attractive to firm 1. When $\gamma\theta>\widehat{\gamma\theta}$, firm 1's benefit from raising its chance to block firm 2 from using the new technology exceeds the associated loss of technological advantage and hence firm 1 files for a patent.

Proposition 1 also shows that the threshold $\widehat{\gamma\theta}$ is bounded from above by $1-\beta_L/\beta_H$. This implies that we should expect more patent applications when (i) β_L is high (PP creates a relatively small technological spillover so firm 1 does not lose much by filing for a patent), and (ii) β_H is low (firm 1's interim knowledge gives it only a small advantage over firm 2 and hence firm 1 has little to lose by filing).

4. Confidential filing (CF)

Absent filing, the expected payoffs of the two firms are still given by Eqs. (3) and (4) and hence the Nash equilibrium in the no-filing subgame continues to be (q_{NF}^1, q_{NF}^2). Moreover, firm 1's expected payoff when it files for a patent continues to be given by Eq. (1) because it can still prevent firm 2 from bringing the new technology to the product market with probability $\gamma\theta$, irrespective of whether its patent application is made public. Hence, the best-response function of firm 1 in the filing subgame remains $R^1(q^2|F)$, exactly as in the PP system.

The only difference between the PP and the CF systems is that now, firm 2's expected payoff in the filing subgame is no longer given by Eq. (2); instead it is given by

$$\begin{aligned}\bar{\pi}^2\left(q^1,q^2|F\right) &= q^1\left[q^2(1-\gamma\theta)\pi_{yy}+\left(1-q^2(1-\gamma\theta)\right)\pi_{ny}\right]\\ &\quad+\left(1-q^1\right)\left[q^2(1-\gamma\theta)\pi_{yn}+\left(1-q^2(1-\gamma\theta)\right)\pi_{nn}\right]-\beta_\theta C\left(q^2\right),\end{aligned}\tag{5}$$

where $\beta_\theta\equiv\theta\beta_M+(1-\theta)\beta_H$. This expression differs from Eq. (2) only in firm 2's cost of R&D, which is now higher and given by $\beta_\theta C(q^2)$ instead of $\beta_L C(q^2)$. The reason for this is that under the CF system, there is a technological spillover only when a patent is actually granted. This event occurs with probability θ; with probability $1-\theta$, firm 1's patent application is rejected and there is no spillover.

The best-response function of firm 2 in the filing subgame, $\bar{R}^2(q^1|F)$, is defined implicitly by $\frac{\partial\bar{\pi}^2(q^1,q^2|F)}{\partial q^2}=0$. Assumptions A1 and A2 ensure that it is well defined and single valued. Moreover, it is downward sloping in the (q^1,q^2) space (q^1 and q^2 are strategic substitutes) if $\Pi>0$ and upward sloping (q^1 and q^2 are strategic complements) if $\Pi<0$. A Nash equilibrium in the filing subgame, $(\bar{q}_F^1, \bar{q}_F^2)$, is determined by the intersection of $R^1(q^2|F)$ and $\bar{R}^2(q^1|F)$. Assumptions A1 and A2 ensure that $(\bar{q}_F^1, \bar{q}_F^2)$ is unique and lies inside the unit square.

To examine the effect of patent protection on the R&D investments, note from Eq. (5) that the likelihood that firm 1 gets a patent, θ, affects the filing subgame not only through the effective patent protection, $\gamma\theta$, but also through firm 2's cost of R&D. Hence, unlike the PP system, now γ and θ do not have the exact same effect on the equilibrium. We begin by noting that as θ increases, firm 2 is less likely to use the new technology in the product market, so its marginal benefit from R&D falls. But since firm 2 is also more likely to get access to firm 1's interim knowledge, its marginal cost of R&D falls as well. To examine the net effect, note that

$$\begin{aligned}\frac{\partial^2\bar{\pi}^2\left(q^1,q^2|F\right)}{\partial q^2\partial\theta} &= -\gamma\left[q^1\left(\pi_{yy}-\pi_{ny}\right)+\left(1-q^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right]-(\beta_M-\beta_H)C'\left(q^2\right)\\ &= \frac{\beta_H}{\beta_\theta}\left[q^1\left(\pi_{yy}-\pi_{ny}\right)+\left(1-q^1\right)\left(\pi_{yn}-\pi_{nn}\right)\right]\left[\left(1-\frac{\beta_M}{\beta_H}\right)-\gamma\right],\end{aligned}$$

where the second equality follows by substituting for $C'(q^2)$ from the first order condition, $\frac{\partial\bar{\pi}^2(q^1,q^2|F)}{\partial q^2}=0$ and rearranging terms. Hence, when θ increases, $\bar{R}^2(q^1|F)$ shifts inward if $\gamma>1-\beta_M/\beta_H$ and outward if $\gamma<1-\beta_M/\beta_H$. As for firm 1, note that $\frac{\partial^2\pi^1(q^1,q^2|F)}{\partial q^1\partial\theta}=\gamma q^2\Pi$, so an increase in θ shifts $R^1(q^2|F)$ outward if $\Pi>0$ and inward if $\Pi<0$. Hence, when $\gamma>1-\beta_M/\beta_H$, the situation is similar to the PP case: $\bar{q}_F^1$ increases with θ if $\Pi>0$ and decreases if $\Pi<0$, while $\bar{q}_F^2$ always decreases with θ irrespective of Π. On the other hand, when $\gamma<1-\beta_M/\beta_H$, an increase in θ has an ambiguous effect on the R&D investments.

As for γ, its effect on the R&D investments is similar to the effect of $\gamma\theta$ under the PP system. That is, $\bar{q}_F^1$ increases with γ if $\Pi>0$ and decreases with γ if $\Pi<0$, while $\bar{q}_F^2$ always decreases with γ irrespective of Π. Using $\bar{\pi}_F^1\equiv\pi^1(\bar{q}_F^1, \bar{q}_F^2|F)$ and $\bar{\pi}_F^2\equiv\pi^2(\bar{q}_F^1, \bar{q}_F^2|F)$ to denote the equilibrium payoffs in the filing subgame, and recalling that as in Section 3, the equilibrium payoffs in the no-filing subgame are π_{NF}^1 and π_{NF}^2, we can prove the following result:

Proposition 2. *(Firm 1's filing decision under the CF system.) For each $\theta>0$, there exists a unique critical value of γ, denoted $\hat{\gamma}$, where $\hat{\gamma}\in(0,1-\beta_\theta/\beta_H)/\theta$, such that $\bar{\pi}_F^1\gtreqless\pi_{NF}^1$* as $\gamma\gtreqless\hat{\gamma}$.

Proposition 2 implies that given the likelihood of getting a patent, θ, firm 1 files for a patent under the CF system if and only if the likelihood that the patent will be upheld in court exceeds a threshold level, $\hat{\gamma}$, which is bounded from above by $(1-\beta_\theta/\beta_H)/\theta$.

5. The implications of PP for R&D, patenting, and welfare

Having examined the two filing systems in isolation, we now compare them in order to determine the impact of PP on firm 1's propensity to file for a patent on its interim knowledge, on the R&D investments of the two firms, and on consumer surplus and social welfare.

5.1. The effect of PP on patenting behavior and on the R&D investments

As a preliminary step, we begin by comparing the equilibrium R&D investments and expected payoffs under the two filing systems, assuming that firm 1 files for a patent (note however that firm 1 need not have the same propensity to file for a patent under the two systems). We do not need to make a similar comparison when firm 1 does not file for a patent since then PP is irrelevant.