Title: Intellectual Property and Product Market Competition Regulations in a Model with Two R&D Performing Sectors

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Abstract: I analyze the impact of intellectual property and product market competition regulations on innovation and long-run growth in an endogenous growth model with two R&D performing sectors. I show that strengthening intellectual property rights and competition in a sector increases its R&D investments. However, these policies adversely affect R&D investments in the other sector because of increased factor competition between the sectors. As a result, the overall impact of such policies on economic growth is ambiguous. I perform a numerical exercise in an attempt to resolve this ambiguity. This exercise suggests that strengthening intellectual property rights increases economic growth, but higher competition has a very limited effect on growth.

Keywords: Intellectual Property Regulation; Product Market Regulation; Two R&D Sectors; Endogenous Growth

1 Introduction

The analysis of the effects of intellectual property and product market competition regulations on innovation is deeply rooted in industrial organization literature (e.g., Nordhaus, 1969, Gilbert and Shapiro, 1990, Chang, 1995, Matutes, Regibeau, and Rockett, 1996, Vives, 2008). Traditionally, studies in industrial organization have considered the effects of such regulations in partial equilibrium frameworks. A large number of recent studies extend this analysis and examine the effects of intellectual property and product market competition regulations on innovation and growth in general equilibrium frameworks featuring one R&D performing sector (e.g., Smulders and van de Klundert, 1995, Yang and Maskus, 2001, O'Donoghue and Zweimüller, 2004, Chu and Pan, 2013).

These studies have provided answers to a number of important questions, such as "What are the optimal intellectual property regulation and product market structure?". Yet, the frameworks used in these studies are not well suited for the analysis of the effects of sector specific intellectual property and product market competition regulations. These frameworks are also not well suited for showing how such regulations in a sector can affect innovation and growth in other sectors. Taking sectoral heterogeneity into consideration can be important because, for example, the regulation of intellectual property has historically been different across the goods and services sectors. Patents on software and business methods are relatively recent phenomena and have proved of great relevance, above all, to the services sector (Tamura, Sheehan, Martinez, and Kergroach, 2005).[1] The cross-sector effects can also shed further light on the likely effects of country-level changes in intellectual property and product market competition regulations.

In this paper, I derive a stylized endogenous growth model with two R&D performing sectors and analyze the impact of intellectual property and product market competition regulations on innovation and growth in the long-run. Each firm in the model has its own product line and can engage in in-house R&D, which then drives long-run growth. In a firm, innovation enhances firm-specific knowledge on the process of production (alternatively, it enhances knowledge for the quality of the firm's product). This knowledge is patented. The firms compete strategically in the output market and finance their R&D expenditures from operating profits. The in-house R&D process builds on the knowledge that the firms possess. In a firm, the R&D process can be improved by combining the firm's own knowledge with the knowledge of other firms from its sector. Intellectual property rights determine the bargaining power of licensors and licensees in the market for knowledge/patents. More specifically, they determine the amount of knowledge that firms can obtain without (appropriate) compensation and the amount of knowledge that firms can license for R&D. Product market regulations determine competitive pressures and strategic interactions among firms in the product market. I assume that intellectual property and product market regulations can be sector specific, as well as economy-wide.

In such a setup, I show that policies, which strengthen intellectual property rights and increase product market competition in a sector, increase its R&D investments and growth. These results mirror the results from a similar one-sector model (see, Jerbashian, 2016). R&D investments increase because stronger intellectual property rights increase the appropriated returns on R&D and higher competition increases sales and, as a consequence, the marginal product of innovation grows. However, these policies adversely affect R&D investments in the other sector. R&D investments in the other sector decline because of increased factor competition between the sectors.

A notable implication of this result is that uniform and economy-wide changes in intellectual property rights and competition have ambiguous effects on long-run growth. Similarly, the impact of strengthening intellectual property rights and increasing product market competition in a sector on economic growth is ambiguous.

In this model, long-run growth necessarily increases with stronger intellectual property rights and competition in a sector if two conditions are met. The sector has the highest weight in final output and the positive effect of these regulations on its R&D investments and growth outweigh their negative effect on R&D investments and growth in the other sector. For example, dividing the economy into the goods and services sectors, which is common in aggregate-level studies, would not help resolve this ambiguity because these positive and negative effects are not readily identifiable. I make a step toward better informed long-run policy implications from the model and perform a simple calibration exercise for the goods and services sectors in Germany, the UK, and the US. The results from this exercise suggest that economic growth in these countries increases with stronger intellectual property rights in the goods and services sectors. Such results hold when property rights are strengthened in one of the two sectors and in both sectors. They hold because stronger property rights in a sector have a large positive effect on its growth and relatively small negative effect on the other sector. However, economic growth almost does not change with a higher level of competition in these sectors because the positive effects of higher competition in a sector are almost fully offset by the negative effects in the other sector. This result holds when competition is intensified in one of the two sectors and in both sectors.

This paper is closely related to Goh and Olivier (2002) and Chu (2011). Goh and Olivier (2002) analyze the effects of changing the strength of intellectual property rights in a growth model with two vertically related sectors and Romer (1990) style R&D and firm entry. Chu (2011) analyzes such effects in a growth model with two (horizontally related) sectors and Aghion and Howitt (1992) style R&D and firm entry/exit. The policy instrument governing intellectual property rights in both papers is patent breadth, which is defined by the power of patentees in the product market. The analysis of this paper is complementary to the analyses and results of Goh and Olivier (2002) and Chu (2011) in a number of ways. In contrast to the models of these papers, R&D in a firm improves the production process (or the quality) of its good and is performed in-house by the firm in the model of the current paper. This modeling choice is motivated by an observation that incumbent firms are responsible for sizeable portions of innovation, patenting and cross-licensing activities. For example, Foster, Haltiwanger, and Syverson (2008) document that productivity growth in incumbent firms accounts for from a quarter to almost a half of productivity growth at the industry-level (see also Bartelsman and Doms, 2000, and references therein). Furthermore, in the model of this paper, the regulation of intellectual property is distinct from the regulation of product market. The regulation of intellectual property affects the bargaining power of firms in the market for patents/knowledge. The regulations of interactions among high-tech firms such as Apple, Google, and Intel in product and patent markets can provide seemingly appropriate examples motivating such a separation. For instance, the regulations of dominant firms imposed by the Federal Trade Commission primarily affect their interactions in product markets (e.g., search engines, online-market platforms, hardware). Meanwhile, the regulations governing patent litigations and essential patents imposed by the US Patent and Trademark Office affect their interactions in patent markets.[2] In this respect, the motivation for the joint analysis of these regulations is that they are commonly thought to have a direct impact on innovation and growth (see, e.g., Claessens and Laeven, 2003, Griffith, Harrison, and Simpson, 2010). Finally, this paper also performs a simple quantitative analysis for the goods and services sectors.

Methodologically, this paper is related to studies that incorporate in-house R&D in growth models (e.g., Smulders and van de Klundert, 1995, van de Klundert and Smulders, 1997, Peretto, 1996, 1998a,b, Peretto and Connolly, 2007). It is also related to studies that consider pricing, selling, and licensing patents in growth models (e.g., O'Donoghue and Zweimüller, 2004, Chantrel, Grimaud, and Tournemaine, 2012, Akcigit, Celik, and Greenwood, 2016, Jerbashian, 2016). These studies have analyzed, for example, how strategic interactions in product markets and imperfect verification and exclusion, bargaining power and, in general, efficiency in the patent markets affect innovation and economic growth. The current paper contributes to these studies by extending the analysis and results to a two-sector framework, which features cross-licensing of patents. It shows that the results from one-sector models might not be readily generalized if there is factor competition between the sectors.

Having a focus on long-run growth, the analysis of this paper omits potential welfare effects of intellectual property and product market competition regulations. Judd (1985), Futagami and Iwaisako (2007), Chu (2009) and Jerbashian (2016), among others, analyze the welfare effects of intellectual property regulations. In turn, Forni, Gerali, and Pisani (2010), Eggertsson, Ferrero, and Raffo (2014), and Papageorgiou and Vourvachaki (2017) offer a detailed account of the welfare implications of product market regulations in large, comprehensive frameworks. The frameworks of these latter studies, however, do not feature sector specific endogenous changes in technology. My quantitative results suggest that this is not a significant omission at least from the perspective of long-run growth because product market regulations are unlikely to affect it.[3]

The results of this paper also have implications for the empirical analysis of the effects of intellectual property regulations and the intensity of competition on innovation and growth in a sector (e.g., Blundell, Griffith, and van Reenen, 1999, Aghion, Bloom, Blundell, Griffith, and Howitt, 2005). The results highlight a necessity of taking into account intellectual property regulation and the intensity of competition in the remainder of the economy (or closely related sectors) in such studies.

The next section introduces the model. Section 3 presents the results from the model and a simple calibration exercise. Section 4 concludes. The proofs of the results are offered in the Online Technical Appendix.

2 The Model

Households

The economy is populated by a continuum of identical and infinitely lived households of mass one. The representative household is endowed with a fixed amount of labor L, which it supplies inelastically. The household has a logarithmic utility function and discounts the future streams of utility with rate $\rho > 0$. The utility gains are from the consumption of amount C of consumption goods. The lifetime utility of the household is given by

$$U = \int_{0}^{+\infty} \ln C_t \exp(-\rho t)\, dt. \tag{1}$$

The household maximizes its lifetime utility subject to a budget constraint,

$$\dot{A} = rA + wL - C, \tag{2}$$

where A is the household's asset holdings $[A(0) > 0]$, r and w are the market returns on its asset holdings and labor supply, and the price of C is normalized to 1.

The household's optimal problem implies that consumption adheres to the standard Euler equation,

$$\frac{\dot{C}}{C} = r - \rho. \tag{3}$$

This equation, together with the budget constraint (2), describes the paths of the household's consumption and assets.

Consumption goods are a Cobb-Douglas basket of X_1 and X_2 intermediate goods, where X_1 is a CES aggregate of all products produced in sector 1, x_1, and X_2 is a CES aggregate of all products produced in sector 2, x_2. Sector $k = 1, 2$ produces N_k number of differentiated products. The elasticity of substitution between products in sector k is $\varepsilon_k > 1$. Formally, consumption goods are given by

$$C = X_1^{\sigma_1} X_2^{\sigma_2}, \tag{4}$$

where

$$X_k = \left(\sum_{j=1}^{N_k} x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}} \right)^{\frac{\varepsilon_k}{\varepsilon_k - 1}}, \tag{5}$$

and $\sigma_1 + \sigma_2 = 1$, $\sigma_k > 0$, $\varepsilon_k > 1$, and $k = 1, 2$.

The household optimally combines $\{x_{1,j}\}_{j=1}^{N_1}$ and $\{x_{2,j}\}_{j=1}^{N_2}$ in C. In order to do so, it solves the following problem:

$$\max_{\{x_{k,j}\}_{j=1}^{N_k}} \left\{ C - \sum_{j=1}^{N_1} p_{x_{1,j}} x_{1,j} - \sum_{j=1}^{N_2} p_{x_{2,j}} x_{2,j} \right\} \tag{6}$$

$$s.t.$$

$$(4), (5),$$

where $p_{x_{k,j}}$ is the price of $x_{k,j}$, and $k = 1, 2$. The solution of this problem implies that

$$p_{x_{k,j}} x_{k,j} = \sigma_k C \frac{x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}}{\sum_{j=1}^{N_k} x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}}. \tag{7}$$

This expression characterizes the household's demand for $\{x_{k,j}\}_{j=1}^{N_k}$.

Intermediate Goods Sectors

In both sectors, firms produce distinct products and have Ricardian production technologies. For ease of exposition, it is convenient to describe the model for a firm j from sector k. The production function of the firm j is given by

$$x_{k,j} = \lambda_{k,j}^{\gamma_k} L_{x_{k,j}}, \tag{8}$$

where $\lambda_{k,j}$ measures its productivity (or the quality of its product), $\gamma_k \in (0,1]$, and $L_{x_{k,j}}$ is its labor input. The level of the productivity $\lambda_{k,j}$ indicates the knowledge of the firm j about its production process. This knowledge is patented.

In both sectors, firms can engage in in-house R&D, which allows them to improve their productivity. They hire labor/researchers L_r in order to perform R&D. In a firm, the researchers use the knowledge of the firm and combine it with the knowledge of other firms in its sector to generate new knowledge. Within a sector, firms can license knowledge/patents from each other. There are also knowledge spillovers among firms, and firms obtain some knowledge without compensation. The knowledge production technology of the firm j from sector k is given by

$$\dot{\lambda}_{k,j} = \xi_k \left[\sum_{i=1}^{N_k} \bar{\lambda}_{k,i}^{\alpha_{k,1}} \left(u_{k,j,i} \lambda_{k,i} \right)^{\alpha_{k,2}} \right] \lambda_{k,j}^{1-\alpha_{k,1}-\alpha_{k,2}} L_{r_{k,j}}, \tag{9}$$

where $\xi_k > 0$ is an exogenous productivity level, $\bar{\lambda}_k$ represents the spillovers of knowledge among firms in sector k, $u_{k,j,i}$ is the share of knowledge that the firm j licenses/purchases from firm i and $u_{k,j,j} \equiv 1$. The exponent of the firm's own knowledge $1 - \alpha_{k,1} - \alpha_{k,2}$ is a fixed technological parameter. It determines the structure of the firm's R&D production technology in terms of knowledge inputs. I use $\tilde{\alpha}_k$ to denote

$$\tilde{\alpha}_k = \alpha_{k,1} + \alpha_{k,2} \tag{10}$$

and assume that $\alpha_{k,1} > 0$, $\alpha_{k,2} > 0$ and $\tilde{\alpha}_k < 1$ to have that spillovers, licensing, and the knowledge of the firm are productive in R&D.

The firm j maximizes the present discounted value of its profit streams. Revenues of the firm j are gathered from the supply of its good and license fees on its knowledge/patents. Its costs are labor compensation for production and R&D and license fees it pays for using the knowledge/patents of other firms. Under Cournot competition, the firm chooses quantities taking the demand for its good as given, whereas under Bertrand competition it chooses prices. The optimal problem of firm j is given by

$$V_{k,j} = \max_{\substack{\textit{Cournot}:\ L_{x_{k,j}},L_{r_{k,j}},\left\{u_{k,j,i},u_{k,i,j}\right\}_{i=1;(i\neq j)}^{N_k} \\ \textit{Bertrand}:\ p_{x_{k,j}},L_{r_{k,j}},\left\{u_{k,j,i},u_{k,i,j}\right\}_{i=1;(i\neq j)}^{N_k}}} \left\{ \int_0^{+\infty} \pi_{k,j}(t) \exp\left[-\int_0^t r(s)\, ds\right] dt \right\} \tag{11}$$

$s.t.$

$(7), (8), (9),$

where

$$\begin{aligned} \pi_{k,j} &= p_{x_{k,j}} x_{k,j} - w\left(L_{x_{k,j}} + L_{r_{k,j}}\right) \\ &\quad + \left[\sum_{i=1,i\neq j}^{N_k} p_{\lambda_{k,j}}\left(u_{k,i,j}\lambda_{k,j}\right) - \sum_{i=1,i\neq j}^{N_k} p_{\lambda_{k,i}}\left(u_{k,j,i}\lambda_{k,i}\right)\right], \end{aligned} \tag{12}$$

and $p_{\lambda_{k,j}}$ and $p_{\lambda_{k,i}}$ are the license fees for $u_{k,i,j}$ and $u_{k,j,i}$ shares of $\lambda_{k,j}$ and $\lambda_{k,i}$ patent portfolios.

From the optimal problem, it follows that the demands for labor for production and R&D of the firm j are given by

$$w = \left(1 - \frac{1}{e_{k,j}}\right) p_{x_{k,j}} \frac{x_{k,j}}{L_{x_{k,j}}}, \tag{13}$$

$$w = q_{\lambda_{k,j}} \frac{\dot{\lambda}_{k,j}}{L_{r_{k,j}}}, \tag{14}$$

where $e_{k,j}$ is the elasticity of substitution perceived by the firm j and $q_{\lambda_{k,j}}$ is the shadow value of knowledge accumulation.

The perceived elasticity of substitution depends on the type of competition. It can be shown that under Cournot competition it is given by

$$e_{k,j} = \varepsilon_k \left\{ 1 + \left[\left(\varepsilon_k - 1\right) \frac{x_{i,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}}{\sum_{j=1}^{N_k} x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}} \right] \right\}^{-1}, \tag{15}$$

and under Bertrand competition it is given by

$$e_{k,j} = \varepsilon_k - \left[\frac{\left(\varepsilon_k - 1\right) p_{x_{k,j}}^{1-\varepsilon_k}}{\sum_{j=1}^{N_k} p_{x_{k,j}}^{1-\varepsilon_k}} \right]. \tag{16}$$

From the optimal problem it also follows that the supply of knowledge, the demand for knowledge, and the returns on knowledge accumulation are given by

$$u_{k,i,j} = 1, \tag{17}$$

$$p_{\lambda_{k,i}} = q_{\lambda_{k,j}} \alpha_{k,2} \xi_k \frac{\left[\bar{\lambda}_k^{\alpha_{k,1}} \left(u_{k,j,i}\lambda_{k,i}\right)^{\alpha_{k,2}} \right] \lambda_{k,j}^{1-\alpha_{k,1}-\alpha_{k,2}}}{u_{k,j,i}\lambda_{k,i}} L_{r_{k,j}}, \tag{18}$$

$$\frac{\dot{q}_{\lambda_{k,j}}}{q_{\lambda_{k,j}}} = r - \left(\gamma_k \frac{e_{k,j} - 1}{e_{k,j}} \frac{p_{x_{k,j}}}{q_{\lambda_{k,j}}} \frac{x_{k,j}}{\lambda_{k,j}} + \sum_{i=1, i \neq j}^{N_k} \frac{p_{\lambda_{k,j}}}{q_{\lambda_{k,j}}} u_{k,i,j} + \frac{\partial \dot{\lambda}_{k,j}}{\partial \lambda_{k,j}} \right), \tag{19}$$

where

$$\frac{\partial \dot{\lambda}_{k,j}}{\partial \lambda_{k,j}} = \xi_k \bar{\lambda}_k^{\alpha_{k,1}} L_{r_{k,j}} \times \left\{ \alpha_{k,2} \lambda_{k,j}^{-\alpha_{k,1}} + \left(1 - \tilde{\alpha}_k\right) \left[\sum_{i=1}^{N_k} \left(u_{k,j,i}\lambda_{k,i}\right)^{\alpha_{k,2}} \right] \lambda_{k,j}^{-\alpha_{k,1}-\alpha_{k,2}} \right\}. \tag{20}$$

Firms license the entire portfolio of their patents/knowledge according to equation (17). They do so because there are no costs associated with licensing and there are no strategic considerations in the market for knowledge.[4] In turn, firms are willing to pay a positive fee for licensing knowledge according to equation (18) because that helps them to improve their R&D process. They are also able to obtain some knowledge for free, which is represented by $\bar{\lambda}_k$. I assume that, in equilibrium, these spillovers among firms from sector k are proportional to the average level of knowledge in sector k and are given by

$$\bar{\lambda}_k = \frac{1}{N_k} \sum_{j=1}^{N_k} \lambda_{k,j}, \tag{21}$$

so that, in a symmetric equilibrium, they are the same as the knowledge of any particular firm from sector k.

Stronger intellectual property rights reduce the ability of firms to obtain knowledge without appropriate compensation. In this setup, strengthening intellectual property rights corresponds to weakening spillovers and increasing $\alpha_{k,2}$. Increasing $\alpha_{k,2}$ increases the compensation of licensors and firms' returns on knowledge accumulation and reduces free-riding according to equations (18), (19), and (20). It also reduces $\alpha_{k,1}$ since $\tilde{\alpha}_k$ is fixed. For example, the parameters $\alpha_{k,1}$ and $\alpha_{k,2}$ can be thought to represent the bargaining powers of licensees and licensors in a Nash-bargaining game. The property rights system then governs the bargaining power of the participants in the market for knowledge by establishing, for example, the procedures and settlements in patent litigations (see, for further discussion of this R&D process, Jerbashian, 2016).[5] In the reminder of the text, I use $\alpha_{k,1}$ as the policy instrument for property rights. This parameter represents the inverse of the strength of intellectual property rights since increasing it increases spillovers and reduces $\alpha_{k,2}$. I use $\alpha_{k,1}$ because its value can be directly calibrated for the quantitative exercise.[6]

The markup over marginal costs $1/e_{k,j}$ measures the market power that the firm j has and the perceived elasticity of substitution $e_{k,j}$ measures the competition it faces. Clearly, the level of competition increases with the actual elasticity of substitution ε_k and the number of firms N_k. It is also higher under Bertrand competition than under Cournot competition. I assume that product market regulation is able to affect the perceived elasticity of substitution $e_{k,j}$ by changing either ε_k or N_k or the type of competition. I consider $e_{k,j}$ as an exogenous policy parameter hereafter.

Several modeling choices merit an in-depth discussion. The R&D process (9) does not permit an exchange of knowledge between sectors. I maintain this assumption for two reasons. Abstracting from the exchange of knowledge between sectors allows me to focus on the effect of regulations on innovation and growth through competition for factor inputs. Moreover, patent licensing and citations are usually quite rare across broad sectors compared to patent licensing and citations within sectors (Acemoglu, Akcigit, and Kerr, 2016). I also assume that homogeneous labor is employed in production and R&D in both sectors and that the reallocation of labor from one sector to another does not entail a transfer of knowledge. In this sense, the current framework focuses solely on the accumulation of patentable, disembodied ideas and abstracts from the workers' knowledge and skills. The mobility of labor across sectors is an important assumption. Kambourov and Manovskii (2009) show that skills are occupation specific and are almost independent of sectors. For example, an occupation and a group of workers, which are a reasonable match to this framework, are the physical, mathematical and engineering science professionals (e.g., IT-engineers). These workers are employed almost everywhere (Jerbashian, Slobodyan, and Vourvachaki, 2016).[7] Finally, these assumptions are not uncommon. They are maintained, for example, by Klenow (1996), Goh and Olivier (2002), and Chu (2011).

The R&D process (9) also has the attractive property of allowing the model to have a well-defined balanced growth path, though it leads to scale effects, similarly to R&D processes and models of Goh and Olivier (2002) and Chu (2011). These effects are contentious (Jones, 1999, Jones and Romer, 2010), and, in the quantitative exercise, I follow Chu (2011) and eliminate them setting $L = 1$.[8, 9]

3 Features of the Equilibrium

I focus on a symmetric equilibrium within the intermediate goods sectors. The results correspond to long-run growth, and the analysis is carried out for a balanced growth path.

In a symmetric equilibrium, from equations (7) and (13) it follows that

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{22}$$

where $N_k L_{x_k}$ is the total labor force employed in the production of goods in sector k and

$$D = \frac{1-\sigma_1}{\sigma_1} \frac{e_1}{e_1 - 1} \frac{e_2 - 1}{e_2}. \tag{23}$$

The relation between $N_2 L_{x_2}$ and $N_1 L_{x_1}$ in equation (22) is a generalization of the well known constant shares relation between factor demands in Cobb-Douglas production functions. It coincides with the latter when markups in sectors are zero. According to equation (22), $N_2 L_{x_2}$ increases (decreases) with a higher level of competition in sector 2 (sector 1). This is because, a higher level of competition in sector 2 (sector 1) reduces prices and increases the demand for the goods produced in sector 2 (sector 1).

Combining equation (22) and the labor market clearing condition,

$$L = \sum_{k=1}^{2} \left(N_k L_{x_k} + N_k L_{r_k} \right), \tag{24}$$

gives a relation between production inputs in sector 1 and R&D inputs in both sectors:

$$N_1 L_{x_1} = (1 + D)^{-1} \left(L - \sum_{k=1}^{2} N_k L_{r_k} \right). \tag{25}$$

The returns on knowledge accumulation in sector k can be derived from equations (9), (13), (14), (18), (17), (19), (20), and (21). They are given by

$$\frac{\dot{q}_{\lambda_k}}{q_{\lambda_k}} = r - \frac{\dot{\lambda}_k}{\lambda_k}\left(\frac{N_k L_{x_k}}{N_k L_{r_k}} + 1 - \alpha_{k,1}\right). \tag{26}$$

Combining this relation with equations (3), (5), (8), (13), and (14) gives

$$0 = \rho - \frac{\dot{\lambda}_k}{\lambda_k}\left(\frac{N_k L_{x_k}}{N_k L_{r_k}} - \alpha_{k,1}\right). \tag{27}$$

Labor allocations in sectors can be derived from equations (9), (22), (25), and (27).

Proposition 1. *The labor force allocations to production and R&D are given by*

$$N_1 L_{x_1} = \frac{\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}L + \left(\xi_2\frac{\alpha_{2,1}}{\gamma_2}\frac{1}{\gamma_1} + \xi_1\frac{\alpha_{1,1}}{\gamma_1}\frac{1}{\gamma_2}\right)\rho}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}}, \tag{28}$$

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{29}$$

and

$$N_1 L_{r_1} = \frac{\xi_1\xi_2\frac{\alpha_{2,1}}{\gamma_2}L - \xi_2\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]\frac{\rho}{\gamma_1} + \xi_1\frac{\rho}{\gamma_2}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}}, \tag{30}$$

$$N_2 L_{r_2} = \frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2} + \xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}}. \tag{31}$$

The growth rates in sectors are proportional to the resources invested in R&D and can be derived from equations (8), (9), (30), and (31). In turn, the growth rate of consumption goods (final output) is given by

$$g_C = \sigma_1\gamma_1 g_{\lambda_1} + (1-\sigma_1)\gamma_2 g_{\lambda_2}, \tag{32}$$

where g denotes growth rates. This is a straightforward relation and states that the growth rate of the economy is a weighted average of sectoral growth rates.[10]

The exponent of the firms' own knowledge in the R&D process, $1-\tilde{\alpha}_k$, does not explicitly appear in equilibrium conditions (28)-(31) because the R&D process is homogeneous of degree 1 in knowledge. This is also the reason why $\alpha_{k,2}$ does not appear in these conditions since the value of $\alpha_{k,2}$ is uniquely determined for the given values of $\alpha_{k,1}$ and technological parameter $\tilde{\alpha}_k$. Nevertheless, the value of $\tilde{\alpha}_k$ restricts the sets of possible values of $\alpha_{k,1}$ and $\alpha_{k,2}$ from above given that $\tilde{\alpha}_k = \alpha_{k,1} + \alpha_{k,2}$ and $\alpha_{k,1}, \alpha_{k,2} > 0$.

Corollary 1.

- *The growth rate of sector k increases with the level of competition and with the strength of property rights in sector k: $\partial g_{\lambda_k}/\partial e_k > 0$ and $\partial g_{\lambda_k}/\partial \alpha_{k,1} < 0$.*
- *The growth rate of sector k declines with the level of competition and with the strength of property rights in sector $k-$: $\partial g_{\lambda_k}/\partial e_{k-} < 0$ and $\partial g_{\lambda_k}/\partial \alpha_{k-,1} > 0$.*
- *Resources devoted to the production of goods in sectors 1 and 2 decline with the strength of property rights in sectors 1 and 2: $\partial L_{x_k}/\partial \alpha_{k,1} > 0$ and $\partial L_{x_k}/\partial \alpha_{k-,1} > 0$.*

The first part of the results in this corollary mimics the results from a similar one-sector model. The rate of growth in sector k increases with the level of competition in sector k because higher competition implies higher output and sales (i.e., $\partial L_{x_k}/\partial e_k > 0$), which increases the marginal product of innovation.[11] In turn, the rate of growth in sector k increases with the strength of property rights in sector k because stronger property rights increase the bargaining power of licensors, who carry the innovation, and imply higher returns on innovation.

The second part of the results in this corollary holds because of competition for factor inputs between sectors. A higher level of product market competition in a sector reduces its prices relative to the prices of the rival sector. This increases the demand for labor for production and R&D in that sector and wage rates. Higher wage rates reduce the output of the rival sector according to equation (22), its revenues and the marginal product of innovation. Therefore, they reduce innovation and growth in the rival sector. In turn, stronger property rights in a sector increase its demand for labor for R&D. It then competes more fiercely for R&D inputs in the labor market, which increases wage rates and reduces R&D investments and growth in the rival sector. Higher wage rates are also the reason for the third part of the results in this corollary, since they drain resources devoted to production in both sectors.

These results have implications for regulations targeting long-run growth in the economy. They imply that the effect of an economy-wide, uniform increase in the level of competition and in the strength of property rights on sectoral growth rates and the growth rate of the economy (32) is ambiguous. It depends on the model parameters. They also imply that the growth rate of the economy necessarily increases with the level of competition and the strength of property rights in a sector under two intuitive conditions. The sector has the highest weight in final output, and the positive effect of these regulations on its growth is stronger than the negative effect of these regulations on the growth in the other sector.[12]

These results suggest that it is ultimately an empirical question as to whether uniform changes in intellectual property and competition regulations can increase long-run growth. Similarly, it is an empirical question as to which of the sectors such regulations could target. I make an attempt to provide an answer to these questions and to calibrate the values of the model parameters in the next section.

Quantitative Exercise

I obtain data for the calibration exercise from the EU KLEMS database (O'Mahony and Timmer, 2009). The data have yearly frequency and are for Germany, the UK, and the US. Table 1 offers sample period for each country.

I divide these economies into goods and services sectors and, to maintain notation, I call the goods sector "sector 1" and the services sector "sector 2." I compute the value added share of the goods sector out of total value added. This share has declined over time everywhere. I set σ_1 to be equal to this share in the sample countries in 2007, which is the last year of the sample period. I also set $L = 1$ and $\rho = 0.02$.

To calibrate the value of D, I compute price-cost margins in each sector. The price-cost margin in a sector is defined as the ratio of the difference between output and labor and intermediate costs, on the one hand, and output, on the other [i.e., (Output - Labor and Intermediate Input Costs)/Output]. I take the average of the price-cost margins over the sample years in each sector and country, assign these values to $1/e_k$, and compute D using these values and the value of σ_1.

I use equation (27) to calibrate the values of $\alpha_{k,1}$. This equation can be rewritten in the following way:

$$\alpha_{k,1} = \left[\left(1 - \frac{1}{e_k} \right) \frac{N_k p_{x_k} x_k}{N_k w L_{r_k}} - \frac{\rho}{g_k} \right] \gamma_k, \tag{33}$$

where the first term in the square brackets is the ratio of value added and R&D investments in sector k, adjusted to market power, and g_k is labor productivity growth in sector k. I adopt a broad view of R&D investments and use general investments instead. The reason for this choice is explained in detail below. I compute the ratios of value added and investments in the goods and services sectors in the sample countries and take the averages of these ratios over the sample years. These averages, together with the calibrated values of markups, are used for the first term in the brackets. For g_k, I use the average values of labor productivity growth in the goods and services sectors in the sample countries.[13]

The values of ξ_1 and ξ_2 can be obtained from equations (30) and (31) for given values of $\alpha_{k,1}$ and γ_k. Similarly to the equation (33) for $\alpha_{k,1}$, I rewrite these equations to obtain the labor productivity growth rates:

$$g_1 = \gamma_1 \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}, \tag{34}$$

$$g_2 = \gamma_2 \frac{D \xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} L - \xi_1 \left[\frac{\alpha_{1,1}}{\gamma_1} (1+D) + 1 \right] \frac{\rho}{\gamma_2} + \xi_2 D \frac{\rho}{\gamma_1}}{\xi_1 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}. \tag{35}$$

According to equations (8) and (9), ξ_k and γ_k jointly identify the effect of a marginal increase of investments on labor productivity growth. In fact, the effects of ξ_k and γ_k are not distinguishable in that context. In what follows, I assume that $\gamma_1 = \gamma_2 \equiv \gamma$, which implies that labor productivity growth differences across sectors, for a given level of investment, are due to differences in research productivity ξ_k.

There are four data moments and equations, and I need to identify five parameters, γ, $\alpha_{k,1}$, and ξ_k for $k = 1, 2$. According to equation (33), $\alpha_{k,1}$ increases with γ. I allow γ to freely vary in an interval where $\alpha_{k,1}(\gamma) \in (0,1)$ and obtain the values of $\alpha_{k,1}$ and ξ_k.

This calibration strategy is not without trade-offs and limitations. First, I use general investments instead of R&D investments. There are several reasons for this. The model features expenditures on and income from patent licensing. Currently, there are no comprehensive data for these and data for R&D expenditures can be contaminated by expenditures on licensing. Moreover, this parsimonious model features only R&D investments when broad measures of growth, such as the growth rate of labor productivity, can be more directly linked to general investments than to R&D investments. General investments also tend to be more readily available. Admittedly, however, the use of general investments may obscure the interpretation of $\alpha_{k,1}$. Second, I use equilibrium conditions to pin down the values of the model parameters, which might be problematic as this relatively small model may not provide a very accurate description of the real economy. Fortunately, at least equation (33) does not use the entire general equilibrium structure of the model.

The model then serves the useful purpose of providing a structural interpretation for $\alpha_{k,1}$. All in all, the calibration exercise presented in this section is a first step toward parameterizing the model for a more informed policy discussion.

Table 1 summarizes the values of the model parameters for the sample countries and the goods and services sectors. It also offers labor productivity growth rates in the goods and services sectors, g_k, and the value of g_C, which is a weighted average of labor productivity growth rates in these sectors and is given by equation (32).

[Table 1 somewhere here]

Notwithstanding the limitations, this calibration exercise delivers appealing parameter values and results. A seemingly reassuring result derived from the values of these parameters is that spillovers in the goods sector are lower in the US than in Germany and the UK. This could be expected as the protection of intellectual property in the goods sector is usually considered stronger in the US than in European countries. As compared to the goods sector, spillovers in services in the US are more comparable to spillovers in services in Germany and the UK and, in all countries, they are lower than spillovers in the goods sector. The evident similarity among Germany, the UK and the US could be because of rather comparable levels of patent protection enforcement for business methods and software innovations, which is relatively common in the services sector and is a recent phenomenon. However, the differences between the levels of spillovers in the goods and services sectors might not be solely attributable to the differences in the protection of intellectual property. For example, differences in the levels of tacit knowledge in the goods and services sectors can also contribute to the differences between the levels of spillovers. In the model, the level of tacit knowledge is lower in the goods sector than in the services sector when the exponent of the firms' own knowledge in the R&D process, $1-\tilde{\alpha}_k$, in the goods sector is lower than the exponent in the services sector. This imposes a stricter restriction on the values of $\alpha_{k,1}$ from above in the services sector than in the goods sector.

The values of the markups also seem to fall in a reasonable ballpark. They are very close to the values used, for example, by Forni et al. (2010) and imply that services are less competitive than the goods sector.

A crude way to gain more confidence about this calibration exercise and these numbers is as follows. I compute the ratio of real investments in a sector and the sum of real value added in the goods and services sectors. I take the average of this ratio over time and assume that it roughly corresponds to the amount of investments adjusted to the scale of the economy (i.e., $N_k L_{r_k}$ when $L = 1$). Next, I compute the ratio of labor productivity growth and the value of this ratio. According to equation (9), this is given by

$$g_k / N_k L_{r_k} = \gamma \xi_k. \tag{36}$$

Finally, I compare the values obtained from this exercise with the multiplication of calibrated values of γ and ξ_k. Table 2 offers the results. The differences between the values of $\gamma\xi_k$ obtained in this exercise and by calibration turn out to be surprisingly small.

[Table 2 somewhere here]

I conduct several counterfactual exercises. First, I examine the effect of a 10 percent reduction in $\alpha_{k,1}$ in the goods and services sectors on sectoral growth rates, as well as on the growth rate of final output. As a policy, this corresponds to increasing the strength of property rights in these sectors. Panels A.1, A.2, and A.3 of Table 3 summarize the results in terms of the percentage changes in the growth rates. Strengthening property rights in a sector increases innovation and growth in that sector and reduces innovation and growth in the other sector. The negative effects are quite limited and growth in total output increases with stronger property rights in both sectors. The elasticities of the growth rate and of innovation with respect to the strength of property rights is higher in the goods sector than in services. This result seems intuitive and suggests that the strength of property rights is more important in the goods sector than in services. However, the elasticity of the growth rate of final output with respect to the strength of property rights in the goods sector is virtually the same as the elasticity with respect to the strength of property rights in the services sector. This is because services have a greater weight in the final output. The highest increase in the growth rate of total output can be obtained by increasing the strength of property rights in both sectors. According to Panel A.3 of Table 3, a 10 percent reduction in $\alpha_{1,1}$ and $\alpha_{2,1}$ increases the growth rate of total output by about 8 percent in the sample countries.

[Table 3 somewhere here]

I also examine the effects of a 10 percent reduction of markups $1/e_k$ in the goods and services sectors, which corresponds to a product market regulation that increases competition in these sectors. Panels B.1, B.2, and B.3 of Table 3 summarize the results. Similarly to stronger property rights, a higher level of competition in a sector increases innovation and growth in that sector and reduces innovation and growth in the other sector. However, the effect of a higher level of competition in a sector is weaker than the effect of stronger property rights. Moreover, the positive and negative effects are almost comparable and the growth rate of total output is largely unaffected by stronger competition in either of the sectors. The latter increases slightly with higher competition in the goods sector and falls with higher competition in the services sector.

The results for the regulations of product market competition can be important for at least three reasons. These regulations have non-trivial effects on innovation and growth in similar one-sector models (e.g., Smulders and van de Klundert, 1995, Peretto, 1996, Jerbashian, 2016). Meanwhile, the quantitative results reported here imply that cross-sector effects, stemming from competition for factor inputs, can considerably weaken the role played by these regulations for innovation and long-run growth.[14] Clearly, a higher level of competition can affect economic performance and welfare by improving the allocative/static efficiency. For example, Forni et al. (2010) and Eggertsson et al. (2014) show that, indeed, a higher level of competition in the services sector increases welfare in European countries. These papers do not incorporate sector-level R&D in their models, and my results suggest that this is not a significant omission at least from the perspective of long-run growth. Moreover, these results point to the importance of controlling for competition in the rest of the economy (or in closely related industries) in studies of the impact of competition on innovation and growth in an industry/sector (e.g., Blundell et al., 1999, Aghion et al., 2005).[15]

In Panel C of Table 3, I examine the effect of a 10 percent increase in the strength of property rights and product market competition in both sectors. The results from this exercise are similar to those obtained for a 10 percent increase in the strength of property rights. This holds because increasing the level of product market competition has a rather limited effect on sectoral growth rates.[16]

The effect of increasing product market competition in a sector on the growth rate of the sector is more limited than the effect of strengthening the property rights because increasing competition entails two opposing effects on R&D and growth. Increasing the level of competition in a sector increases the resources devoted to production in that sector, L_x. As a consequence, it increases the marginal product of innovation and the resources devoted to R&D, L_r. On the other hand, however, increasing the level of competition reduces L_r because it reduces the amount of resources that can be devoted to R&D. These positive and negative effects on L_r are of a second order since they follow from the changes in L_x. Moreover, the positive effect is only marginally stronger than the negative effect under the current parametrization of the model. Meanwhile, stronger property rights have a first order effect on R&D and growth. They increase the returns on R&D and L_r.

In the data, the strength of the property rights and the level of competition in the product market can be correlated because, for example, stronger property rights in a sector can restrict the production of close substitutes in that sector. Such a correlation naturally arises in models that consider patent breadth as the instrument of property rights (see, e.g., Goh and Olivier, 2002, Chu, 2011). Regulations increasing patent breadth in these models increase the strength of property rights, but they reduce product market competition. A comparison of the values of markups and $\alpha_{1,1}$ in the US with these values in Germany and the UK can provide evidence of such a pattern. According to the values of $\alpha_{1,1}$, property rights in the goods sector are stronger in the US than in Germany and the UK, where they are of the same order of magnitude. Meanwhile, the level of competition in the goods sector is lower in the US than in Germany and the UK according to the values of $1/e_1$.[17] However, the exact relation between the level of competition and the strength of the property rights is *a priori* ambiguous, and this model is silent about such a relation given its level of abstraction. One way to incorporate such a relation is to assume US values of markups and $\alpha_{k,1}$ for Germany and the UK. The growth rate of final output in Germany and the UK increases when these countries have the same level of property rights and competition in the goods and services sectors as in the US according to Panels D.1 and D.2 of Table 3. Moreover, these results are almost entirely driven by the differences in the strength of property rights and are largely unaffected by the level of competition.[18]

4 Conclusions

In this paper, I analyze the effect of intellectual property and product market competition regulations on innovation and growth in the long-run in an endogenous growth model that features two R&D performing sectors. I show that stronger intellectual property rights and more intensive product market competition in a sector increase its innovation and growth. However, they reduce innovation and growth in the rival sector.

These results imply that the effect of economy-wide changes in intellectual property and product market competition regulations on long-run growth can be ambiguous. Similarly, the effect of changes in intellectual property and competition regulations in a sector on economic growth can be ambiguous.

I attempt to resolve this ambiguity and provide better informed policy implications from the model. To do so, I perform a calibration exercise for the goods and services sectors in Germany, the UK, and the US. The results from this exercise suggest that stronger property rights in the goods and services sectors imply higher economic growth in these countries. Such results hold when property rights are strengthened in one of the sectors, as well as in both sectors. They hold because stronger property rights in a sector have a large positive effect on its growth and a very marginal negative effect on the growth rate of the other sector. However, economic growth almost does not change with a higher level of competition in these sectors because the positive effects of higher competition in a sector are almost fully offset by the negative effects in the other sector. This result holds when competition is intensified in one of the sectors and in both sectors.

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Notes

[1]The division of an economy into goods and services sectors has not been very popular in studies of innovation and growth because services have usually been thought to have low levels of R&D and patenting. According to Tamura et al. (2005), this perception is far from accurate at least in the OECD countries where R&D and patenting have increased sharply in the services sector since the 90s.

[2]Recent examples include the e-book antitrust case, where Apply was forced to pay $450 million in damages, and the AdWord patent infringement case, where Google was forced to pay about $30 million and running royalties of 3.5%.

[3]The agenda of the European Commission includes increasing competition in member states and, in particular, in the services sector. My quantitative results suggest that the effects of such policies on long-run growth are likely to be quite limited.

[4]These assumptions can seem to be strong. They correspond to assuming an undistorted market for knowledge and will not hold if, for example, there are policies/taxes that generate licensing costs. I maintain these assumptions because they help me to focus on the effects of spillovers.

[5]For example, the property rights system affected a recent patent dispute between Apple and Google, where the former sought nearly $2 billion in royalties. Apple and Google decided to settle and engage in cross-licensing in 2014 after Apple was awarded $119.6 million in damages against Samsung, about 10% of the amount Apple requested. Imperfections in the verification and exclusion of the use of patents can affect the bargaining power and account for the decision to settle (Chantrel et al., 2012).

[6]This property rights instrument is complementary to patent breadth, which establishes the minimal difference between an idea and current patents that permits the idea to be patented and produced. In the framework of this paper, the lines of products, patents, and ideas are fixed and all ideas are assumed to be patentable. One way to introduce patent breadth in this framework follows Akcigit et al. (2016) and allows the firms to innovate along multiple lines of ideas.

[7]Evidence for competition for R&D inputs across sectors is scarce, anecdotal, and usually indirect. A recent, notorious example is the collusion of software giants, Apple and Google, and chip maker, Intel, not to poach engineers from each other. This collusion ended with a class-action antitrust suit.

[8]Jerbashian (2016) offers an alternative method for eliminating the scale effects in a similar model, while keeping the inference for knowledge licensing intact. I prefer the current specification because of its analytical versatility.

[9]The R&D process (9) is linear in labor input. Therefore, in the social planner's problem, $L_r = 0$ in the sector which makes the lowest contribution to growth, and this sector does not innovate. I do not present the social planner's problem for the sake of brevity.

[10]The effects of the type of competition, ε_k and N_k $(k = 1, 2)$ on equilibrium outcomes are implicitly captured in D (23). For example, it can be shown that D is lower (higher) under Bertrand competition than under Cournot competition in sector 1 (sector 2).

[11]It can be shown that increasing competition reduces profits (12) and there is a level of competition when profits are equal to zero. Innovation increases with competition till this level and ceases when the level of competition increases from this level. This is consistent with Schumpeter's argument that firms need to be sufficiently large to innovate and generates an inverted U-shape like relation between competition and innovation as in the paper by Aghion et al. (2005).

[12]van de Klundert and Smulders (1999) offer a model with two imperfectly competitive sectors, where one of the sectors engages in R&D. In such a framework, a higher level of competition in the sector that performs (does not perform) R&D increases (reduces) the growth rate of the economy.

[13]I would need to obtain information on the entire structure of knowledge input in the R&D technology (9) in order to calibrate the values of $\tilde{\alpha}_k$ and $\alpha_{k,2}$ separately since $\tilde{\alpha}_k$ does not directly affect the returns on R&D. For this reason, the calibration of the precise value of $\tilde{\alpha}_k$ can be a demanding task, and I prefer using $\alpha_{k,1}$ as the property rights instrument since its value is directly observable from equation (33).

[14]Such an inference can be weaker when there are significant mobility costs across sectors and the production function of intermediate goods (8) exhibits a large level of concavity in labor input.

[15]In the Online Appendix - Further Results, I use the data of Aghion et al. (2005) and offer evidence that innovation in a sector can be negatively affected by competition in closely related sectors. This evidence outlines an area of potentially fruitful future research.

[16]Table A in the Online Appendix - Further Results presents the effects of reducing the strength of property rights and product market competition. In absolute terms, these effects are comparable to the effects of increasing the strength of property rights and product market competition.

[17]Such a pattern also holds for services, albeit to a lesser extent. The value of $\alpha_{2,1}$ is the lowest and the value of $1/e_2$ is the highest in Germany. Nevertheless, the values of $\alpha_{k,1}$ and $1/e_k$ in the UK do not strictly adhere to this pattern.

[18]I perform similar calibration exercises for the models of Goh and Olivier (2002) and Chu (2011). I vary parameters corresponding to patent breadth and discuss the results in detail in the Online Appendix - Further Results.

Tables

Table 1: Sample Period and the Values of the Model Parameters and Sectoral Growth Rates

L	1.000							
ρ	0.020							
	Sample Period	σ_1	$1/e_1$	$1/e_2$	D	g_1	g_2	g_C
Germany	1991–2007	0.311	0.090	0.230	1.873	0.029	0.018	0.021
UK	1970–2007	0.242	0.120	0.140	3.063	0.034	0.015	0.020
US	1977–2007	0.233	0.137	0.223	2.970	0.025	0.012	0.015
	γ	0.020	0.040	0.070	0.100	0.130	0.160	0.180
Germany	$\alpha_{1,1}$	0.111	0.221	0.387	0.553	0.719	0.885	0.996
	$\alpha_{2,1}$	0.036	0.072	0.127	0.181	0.236	0.290	0.326
	ξ_1	33.008	16.504	9.431	6.602	5.078	4.126	3.668
	ξ_2	5.091	2.545	1.455	1.018	0.783	0.636	0.566
UK	$\alpha_{1,1}$	0.113	0.227	0.397	0.567	0.737	0.907	> 1
	$\alpha_{2,1}$	0.050	0.099	0.174	0.248	0.322	0.397	-
	ξ_1	53.169	26.584	15.191	10.634	8.180	6.646	-
	ξ_2	4.707	2.354	1.345	0.941	0.724	0.588	-
US	$\alpha_{1,1}$	0.089	0.179	0.313	0.447	0.582	0.716	0.805
	$\alpha_{2,1}$	0.042	0.084	0.147	0.209	0.272	0.335	0.377
	ξ_1	32.183	16.091	9.195	6.437	4.951	4.023	3.576
	ξ_2	3.664	1.832	1.047	0.733	0.564	0.458	0.407

Note: This table offers the sample period for each country and the calibrated values of the model parameters. It also presents the values of labor productivity growth rates in the sectors, g_k, and the value of g_C, which is given by $g_C = \sigma_1 g_1 + (1-\sigma_1)\, g_2$. The values of parameters are not reported for the UK when $\gamma = 0.180$ because the value of $\alpha_{1,1}$ for the UK is greater than 1. The goods sector is sector 1 and the services sector is sector 2. The goods sector is comprised of A, B, C, D, E, and F 1-digit ISIC industries, and the services sector is comprised of the remainder 1-digit ISIC industries.

Table 2: Calibrated Values of $\gamma\xi_1$ and $\gamma\xi_2$ and their Values Implied by Equation (36)

	$\gamma\xi_1$		$\gamma\xi_2$	
	Calibrated	Implied by (36)	Calibrated	Implied by (36)
Germany	0.660	0.585	0.102	0.091
UK	1.063	0.634	0.094	0.100
US	0.644	0.530	0.073	0.075

Note: This table offers the values of $\gamma\xi_1$ and $\gamma\xi_2$ computed from the calibration exercise and the values of these parameters implied by equation (36) and computed as the ratio of labor productivity growth and the ratio of real investments in a sector and the sum of real value added in the goods and services sectors. The values of $\gamma\xi_1$ and $\gamma\xi_2$ computed from the calibration exercise are invariant to the choice of the value of γ. The goods sector is sector 1 and the services sector is sector 2.

Table 3: The Growth Effects of Strengthening Intellectual Property Rights and Increasing Product Market Competition

	A.1: -10%Δ in $\alpha_{1,1}$			A.2: -10%Δ in $\alpha_{2,1}$			A.3: -10%Δ in $\alpha_{1,1}$ and $\alpha_{2,1}$		
%Δ in	g_1	g_2	g_C	g_1	g_2	g_C	g_1	g_2	g_C
Germany	10.568	-0.706	4.089	-1.891	8.075	3.836	8.491	7.326	7.821
UK	10.715	-0.496	4.177	-1.760	8.393	4.161	8.776	7.865	8.245
US	10.622	-0.683	3.771	-1.763	8.076	4.200	8.684	7.352	7.877
	B.1: -10%Δ in $1/e_1$			B.2: -10%Δ in $1/e_2$			B.3: -10%Δ in $1/e_1$ and $1/e_2$		
%Δ in	g_1	g_2	g_C	g_1	g_2	g_C	g_1	g_2	g_C
Germany	0.785	-0.461	0.069	-2.336	1.371	-0.206	-1.561	0.916	-0.137
UK	1.174	-0.447	0.229	-1.399	0.532	-0.273	-0.236	0.090	-0.046
US	1.460	-0.631	0.193	-2.592	1.120	-0.343	-1.155	0.499	-0.153
	C: -10%Δ in $\alpha_{1,1}$, $\alpha_{2,1}$, $1/e_1$, and $1/e_2$			D.2: US values for $\alpha_{1,1}$, $\alpha_{2,1}$, $1/e_1$, and $1/e_2$			D.1: US values for $\alpha_{1,1}$ and $\alpha_{2,1}$		
%Δ in	g_1	g_2	g_C	g_1	g_2	g_C	g_1	g_2	g_C
Germany	6.782	8.307	7.659	19.348	-9.114	2.992	25.337	-11.791	4.001
UK	8.518	7.962	8.193	30.870	9.242	18.257	22.045	12.341	16.386
US	7.420	7.889	7.705						

Note: This table offers the effects of strengthening intellectual property rights (10% reduction in $\alpha_{k,1}$) and increasing product market competition (10% reduction in $1/e_k$) on labor productivity growth rates in the goods and services sectors (g_1 and g_2) and on the growth rate of the economy [$g_C = \sigma_1 g_1 + (1-\sigma_1) g_2$]. It also offers the growth effects of using US values of $\alpha_{k,1}$ and $1/e_k$ for Germany and the UK. The effects are computed as percentage changes from the values of growth rates offered in Table 1. The goods sector is sector 1 and the services sector is sector 2.

Online Appendix to "Intellectual Property and Product Market Competition Regulations in a Model with Two R&D Performing Sectors"

Vahagn Jerbashian*

A Online Technical Appendix

Definition of Equilibrium

The decentralized equilibrium in this model is the paths of the quantities

$$\left\{C, A, \left\{X_k, \left\{x_{k,j}, L_{x_{k,j}}, L_{r_{k,j}}, \lambda_{k,j}, \bar{\lambda}_{k,j}\right\}_{j=1}^{N_k}, \left\{u_{k,i,j}, u_{k,j,i}\right\}_{j,i=1(j\neq i)}^{N_k}\right\}_{k=1,2}\right\}$$

and prices

$$\left\{r, w, \left\{\left\{p_{x_{k,j}}, p_{\lambda_{k,j}}, p_{\lambda_{k,i}}\right\}_{j,i=1}^{N_k}\right\}_{k=1,2}\right\}$$

such that:

- The household chooses C, $\left\{X_k, \left\{x_{k,j}, L_{x_{k,j}}, L_{r_{k,j}}\right\}_{j=1}^{N_k}\right\}_{k=1,2}$, and the evolution of A to maximize its utility, given $r, w, \left\{\left\{p_{x_{k,j}}\right\}_{j=1}^{N_k}\right\}_{k=1,2}$ and the current value of A.

- The firm $j = 1, ..., N_k$ in sector $k = 1, 2$ maximizes its value, given the current value of $\lambda_{k,j}$ and $\left\{p_{\lambda_{k,j}}, p_{\lambda_{k,i}}\right\}_{j,i=1(j\neq i)}^{N_k}$.

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- It chooses $\left\{L_{x_{k,j}}, L_{r_{k,j}}\right\}_{j=1}^{N_k}$ and $\{u_{k,i,j}, u_{k,j,i}\}_{j,i=1(j\neq i)}^{N_k}$ subject to the inverse demand for its product under Cournot competition.
- It chooses $\left\{p_{x_{k,j}}, L_{r_{k,j}}\right\}_{j=1}^{N_k}$ and $\{u_{k,i,j}, u_{k,j,i}\}_{j,i=1(j\neq i)}^{N_k}$ subject to the demand for its product under Bertrand competition.

- Labor market clears:

$$L = \sum_{k=1}^{2} \left(N_k L_{x_k} + N_k L_{r_k}\right). \tag{1}$$

- Knowledge market in each sector $k = 1, 2$ clears:

$$\sum_{j=1}^{N_k} \sum_{i=1, i\neq j}^{N_k} u_{k,i,j} \lambda_{k,j} = \sum_{j=1}^{N_k} \sum_{i=1, i\neq j}^{N_k} u_{k,j,i} \lambda_{k,i}. \tag{2}$$

- Intermediate goods and asset markets clear $\left(\dot{A} = 0\right)$.

- Spillovers are firm independent and are given by $\bar{\lambda}_k = \frac{1}{N_k} \sum_{j=1}^{N_k} \lambda_{k,j}$.

Proof of Proposition 1

I use equations (7) and (13) to obtain a relation between labor force allocations in sectors 1 and 2 in a symmetric equilibrium in these sectors:

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{3}$$

where D is given by equation (23). This relation, together with the labor market clearing condition (24) implies that labor force allocations to production in sectors

1 and 2 are given by

$$N_1 L_{x_1} = (1+D)^{-1}\left(L - \sum_{k=1}^{2} N_k L_{r_k}\right), \tag{4}$$

$$N_2 L_{x_2} = D\,(1+D)^{-1}\left(L - \sum_{k=1}^{2} N_k L_{r_k}\right). \tag{5}$$

All variables grow at constant rates on a balanced growth path. From equations (9), (4), and (5), it follows that labor allocations are constant on that path.

I use equations (9), (13), (14), (18), (17), (20), and (21) to rewrite relation (19) in the following way:

$$\frac{\dot{q}_{\lambda_k}}{q_{\lambda_k}} = r - \frac{\dot{\lambda}_k}{\lambda_k}\left(\gamma_k \frac{N_k L_{x_k}}{N_k L_{r_k}} + 1 - \alpha_{k,1}\right). \tag{6}$$

From the Euler equation (3) and equations (13), (14), and (7), it follows that another relation for the returns on knowledge accumulation is

$$\frac{\dot{q}_{\lambda_k}}{q_{\lambda_k}} = r - \rho - \frac{\dot{\lambda}_k}{\lambda_k}. \tag{7}$$

I combine these two relations to obtain

$$0 = \rho - \frac{\dot{\lambda}_k}{\lambda_k}\left(\gamma_k \frac{N_k L_{x_k}}{N_k L_{r_k}} - \alpha_{k,1}\right). \tag{8}$$

This expression, together with equations (9), (4) and (5), determines labor force allocations in the balanced growth path equilibrium. The labor force allocations are given by

$$N_1 L_{x_1} = \frac{\xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2} L + \left(\xi_2 \frac{\alpha_{2,1}}{\gamma_2}\frac{1}{\gamma_1} + \xi_1 \frac{\alpha_{1,1}}{\gamma_1}\frac{1}{\gamma_2}\right)\rho}{\xi_1 \xi_2 \left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D) + D\right] + \frac{\alpha_{2,1}}{\gamma_2}\right\}}, \tag{9}$$

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{10}$$

and

$$N_1 L_{r_1} = \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2}(1+D) + D\right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_1 \xi_2 \left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D) + D\right] + \frac{\alpha_{2,1}}{\gamma_2}\right\}}, \tag{11}$$

$$N_2 L_{r_2} = \frac{D \xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} L - \xi_1 \left[\frac{\alpha_{1,1}}{\gamma_1}(1+D) + 1\right] \frac{\rho}{\gamma_2} + \xi_2 D \frac{\rho}{\gamma_1}}{\xi_1 \xi_2 \left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D) + D\right] + \frac{\alpha_{2,1}}{\gamma_2}\right\}}. \tag{12}$$

I assume that parameter values are such that $N_1 L_{r_1}$ and $N_2 L_{r_2}$ are positive so that both sectors innovate in equilibrium.

In order to obtain relation (33), I use equation (8) and the fact that labor productivity growth in sector k is given by

$$g_k = \gamma_k g_{\lambda_k}, \tag{13}$$

where g denotes growth rate.

Proof of Corollary 1

The growth rate of λ_k can be derived from equation (9):

$$g_{\lambda_k} = \xi_k N_k L_{r_k}, \tag{14}$$

where $N_1 L_{r_1}$ and $N_2 L_{r_2}$ are given by equations (11) and (12).

Using equations (9)-(12), it can be shown that

$$\frac{\partial}{\partial D} N_1 L_{x_1} = - \frac{\xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} \frac{\alpha_{2,1}}{\gamma_2} L + \xi_1 \frac{\alpha_{1,1}}{\gamma_1} \frac{\rho}{\gamma_2} + \xi_2 \frac{\alpha_{2,1}}{\gamma_2} \frac{\rho}{\gamma_1}}{\xi_1 \xi_2 \left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D) + D\right] + \frac{\alpha_{2,1}}{\gamma_2}\right\}^2} \frac{\alpha_{1,1}}{\gamma_1} \left(\frac{\alpha_{2,1}}{\gamma_2} + 1\right) < 0, \tag{15}$$

$$\frac{\partial}{\partial D} N_1 L_{r_1} = - \frac{\xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} \frac{\alpha_{2,1}}{\gamma_2} L + \xi_1 \frac{\alpha_{1,1}}{\gamma_1} \frac{\rho}{\gamma_2} + \xi_2 \frac{\rho}{\gamma_1} \frac{\alpha_{2,1}}{\gamma_2}}{\xi_1 \xi_2 \left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D) + D\right] + \frac{\alpha_{2,1}}{\gamma_2}\right\}^2} \left(\frac{\alpha_{2,1}}{\gamma_2} + 1\right) < 0, \tag{16}$$

and

$$\frac{\partial}{\partial D}N_2L_{x_2} = \frac{\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}L + \xi_1\frac{\alpha_{1,1}}{\gamma_1}\frac{\rho}{\gamma_2} + \xi_2\frac{\alpha_{2,1}}{\gamma_2}\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2}\frac{\alpha_{2,1}}{\gamma_2}\left(\frac{\alpha_{1,1}}{\gamma_1}+1\right) > 0, \tag{17}$$

$$\frac{\partial}{\partial D}N_2L_{r_2} = \frac{\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}L + \xi_1\frac{\alpha_{1,1}}{\gamma_1}\frac{\rho}{\gamma_2} + \xi_2\frac{\rho}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2}\left(\frac{\alpha_{1,1}}{\gamma_1}+1\right) > 0. \tag{18}$$

According to equation (23), D declines with e_1 and increases with e_2. Therefore, output, R&D, and growth in sector k increase with the level of competition in sector k and decline with the level of competition in the other sector. A uniform increase in competition in both sectors can either increase or reduce D depending on the values of e_1 and e_2. Let $\mathbf{e} = (e_1, e_2)$,

$$\frac{\partial}{\partial \mathbf{e}}D = \frac{1-\sigma}{\sigma}\frac{1}{e_2(e_1-1)}\frac{e_1(e_1-1)-e_2(e_2-1)}{e_2(e_1-1)}. \tag{19}$$

The partial derivative of the growth rate of consumption goods (final output) with respect to D can be derived from equations (4), (5), (8), (16), and (18). It is given by

$$\begin{aligned}\frac{\partial}{\partial D}g_C = &-\frac{\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}L + \xi_1\frac{\alpha_{1,1}}{\gamma_1}\frac{\rho}{\gamma_2} + \xi_2\frac{\rho}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} \\ &\times\left[\sigma_1\gamma_1\xi_1\left(\frac{\alpha_{2,1}}{\gamma_2}+1\right)-(1-\sigma_1)\gamma_2\xi_2\left(\frac{\alpha_{1,1}}{\gamma_1}+1\right)\right].\end{aligned} \tag{20}$$

The sign of this expression depends on the values of the model parameters. This means that the effect of changing the level of competition in sector k and/or uniformly changing the level of competition in both sectors on long-run growth depends on the model parameters. For example, $\partial g_C/\partial D$ is negative (positive) when $\sigma_1 > 1/2$ ($\sigma_1 < 1/2$) and the effect of changing the level of competition on growth in sector 2 is higher (lower) than this effect in sector 1. It is necessarily negative (positive) if $\sigma_1 = 1/2$, $\gamma_1 = \gamma_2$, $\alpha_{2,1} = \alpha_{1,1}$, and $\xi_1 > \xi_2$ ($\xi_1 < \xi_2$).[1]

In a special case when $e_1 = e_2$, D does not depend on the levels of competition in sectors 1 and 2. This implies that the level of competition does not matter for resource allocations in the economy and imperfect/oligopolistic competition does not distort them. Such a result holds because all price levels are equally affected by imperfect competition when $e_1 = e_2$ and the relative prices are not. Decentralized equilibrium allocations are socially optimal in a similar one-sector model when relative prices are not distorted and $\alpha_{\cdot,1} = 0$ (e.g., when $\sigma = 1$ in the model of Jerbashian, 2016).[2] In contrast, in this two sector model allocations in decentralized equilibrium are not socially optimal. Both sectors innovate in decentralized equilibrium because of private incentives. However, the social planner would choose $L_r = 0$ and no innovation in the sector which has the lowest contribution to growth. It would do so because R&D process (9) is linear in labor input.

The partial derivatives of labor force allocations with respect to $\alpha_{k,1}$ can be readily derived from equations (9)-(12). The partial derivatives with respect to $\alpha_{1,1}$ are given by

$$\frac{\partial}{\partial \alpha_{1,1}} N_1 L_{x_1} = \frac{\alpha_{2,1}}{\gamma_2} \frac{1}{\gamma_1} \frac{\xi_1 \xi_2 L \frac{\alpha_{2,1}}{\gamma_2} - \left\{ \xi_2 \frac{1}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] - \xi_1 \frac{1}{\gamma_2} \right\} \rho}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} > 0, \tag{21}$$

$$\begin{aligned} \frac{\partial}{\partial \alpha_{1,1}} N_1 L_{r_1} = &- \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} \frac{1}{\gamma_1} \\ &\times \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] < 0, \end{aligned} \tag{22}$$

$$\frac{\partial}{\partial \alpha_{1,1}} N_2 L_{x_2} = D \frac{\alpha_{2,1}}{\gamma_2} \frac{1}{\gamma_1} \frac{\xi_1 \xi_2 L \frac{\alpha_{2,1}}{\gamma_2} - \left\{ \xi_2 \frac{1}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] - \xi_1 \frac{1}{\gamma_2} \right\} \rho}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} > 0, \tag{23}$$

$$\frac{\partial}{\partial \alpha_{1,1}} N_2 L_{r_2} = \frac{1}{\gamma_1} D \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} > 0. \tag{24}$$

In turn, the partial derivatives with respect to $\alpha_{2,1}$ are given by

$$\frac{\partial}{\partial \alpha_{2,1}} N_1 L_{x_1} = \frac{1}{\gamma_2}\frac{\alpha_{1,1}}{\gamma_1}\frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2}+\xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} > 0, \tag{25}$$

$$\frac{\partial}{\partial \alpha_{2,1}} N_1 L_{r_1} = \frac{1}{\gamma_2}\frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2}+\xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} > 0, \tag{26}$$

$$\frac{\partial}{\partial \alpha_{2,1}} N_2 L_{x_2} = D\frac{1}{\gamma_2}\frac{\alpha_{1,1}}{\gamma_1}\frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2}+\xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} > 0, \tag{27}$$

$$\begin{aligned}\frac{\partial}{\partial \alpha_{2,1}} N_2 L_{r_2} = &-\frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2}+\xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} \\ &\times\frac{1}{\gamma_2}\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right] < 0.\end{aligned} \tag{28}$$

These results imply that reducing $\alpha_{k,1}$ increases R&D and growth in sector k and reduces R&D and growth in the other sector.

The effect of a uniform change in $\alpha_{1,1}$ and $\alpha_{2,1}$ on the growth rate in sector k is given by the sum of the partial derivatives of $N_k L_{r_k}$ with respect to $\alpha_{1,1}$ and $\alpha_{2,1}$. The sign and the magnitude of this effect depend on the model parameters.

The partial derivatives of the growth rate of consumption goods (final output) with respect to $\alpha_{1,1}$ and $\alpha_{2,1}$ can be derived from equations (4), (5), (8), and (21)-(28). They are given by

$$\begin{aligned}\frac{\partial}{\partial \alpha_{1,1}} g_C = &-\frac{1}{\gamma_1}\frac{\xi_1\xi_2\frac{\alpha_{2,1}}{\gamma_2}L - \xi_2\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]\frac{\rho}{\gamma_1}+\xi_1\frac{\rho}{\gamma_2}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} \\ &\times\left\{\sigma_1\gamma_1\xi_1\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]-(1-\sigma_1)\gamma_2\xi_2 D\right\},\end{aligned} \tag{29}$$

and

$$\frac{\partial}{\partial \alpha_{2,1}} g_C = \frac{1}{\gamma_2} \frac{D\xi_1\xi_2 \frac{\alpha_{1,1}}{\gamma_1} L - \xi_1 \left[\frac{\alpha_{1,1}}{\gamma_1} (1+D) + 1 \right] \frac{\rho}{\gamma_2} + \xi_2 D \frac{\rho}{\gamma_1}}{\xi_1\xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} \times \left\{ \sigma_1 \gamma_1 \xi_1 - \left[\frac{\alpha_{1,1}}{\gamma_1} (1+D) + 1 \right] (1-\sigma_1) \gamma_2 \xi_2 \right\}. \tag{30}$$

The signs of these expressions depend on the values of the model parameters. This means that the effects of changing $\alpha_{1,1}$ and $\alpha_{2,1}$ on long-run growth depend on the model parameters. For example, $\partial g_C / \partial \alpha_{1,1}$ is negative (positive) when $\sigma_1 > 1/2$ ($\sigma_1 < 1/2$) and the effect of changing $\alpha_{1,1}$ on growth in sector 1 is higher (lower) than this effect on growth in sector 2. Both these expressions are negative when $\sigma_1 = 1/2$, $\xi_1 = \xi_2$, and $\gamma_1 = \gamma_2$.

The effect of a uniform change in $\alpha_{1,1}$ and $\alpha_{2,1}$ on g_C is given by the sum of the partial derivatives of g_C with respect to $\alpha_{1,1}$ and $\alpha_{2,1}$. The sign and the magnitude of this effect depend on the model parameters.

B Online Appendix - Further Results

Table A: The Growth Effects of Weakening Intellectual Property Rights and Reducing Product Market Competition

	A.1: 10%Δ in $\alpha_{1,1}$			A.2: 10%Δ in $\alpha_{2,1}$			A.3: 10%Δ in $\alpha_{1,1}$ and $\alpha_{2,1}$		
%Δ in	g_1	g_2	g_C	g_1	g_2	g_C	g_1	g_2	g_C
Germany	-8.724	0.583	-3.375	1.628	-6.952	-3.303	-7.229	-6.401	-6.753
UK	-8.824	0.408	-3.440	1.507	-7.187	-3.563	-7.444	-6.802	-7.070
US	-8.761	0.563	-3.110	1.518	-6.953	-3.616	-7.368	-6.421	-6.794
	B.1: 10%Δ in $1/e_1$			B.2: 10%Δ in $1/e_2$			B.3: 10%Δ in $1/e_1$ and $1/e_2$		
%Δ in	g_1	g_2	g_C	g_1	g_2	g_C	g_1	g_2	g_C
Germany	-1.223	0.024	-0.506	2.437	-1.431	0.214	1.638	-0.962	0.144
UK	-1.494	0.130	-0.547	1.435	-0.546	0.280	0.244	-0.093	0.047
US	-1.856	0.241	-0.585	2.711	-1.171	0.358	1.217	-0.526	0.161
	C: 10%Δ in $\alpha_{1,1}$, $\alpha_{2,1}$, $1/e_1$, and $1/e_2$								
%Δ in	g_1	g_2	g_C						
Germany	-5.721	-7.303	-6.630						
UK	-7.220	-6.888	-7.027						
US	-6.247	-6.912	-6.650						

Note: This table offers the effects of weakening intellectual property rights (10% increase in $\alpha_{k,1}$) and reducing product market competition (10% increase in $1/e_k$) on labor productivity growth rates in the goods and services sectors (g_1 and g_2) and on the growth rate of the economy [$g_C = \sigma_1 g_1 + (1 - \sigma_1)\, g_2$]. The effects are computed as percentage changes in the values of the growth rates presented in Table 1. The goods sector is sector 1 and the services sector is sector 2.

B.1 An Extension of Aghion, Bloom, Blundell, Griffith, and Howitt (2005)

In this section, I use the data and an extension of the empirical methodology developed by Aghion et al. (2005) and present evidence that innovation in an industry can be affected by competition in closely related industries.

Aghion et al. (2005) aim to identify the effect of competition in industries on innovation and growth. They use data from the UK for seventeen 2-digit SIC manufacturing industries for the period 1973–1994. They use the number of citation-weighted patents in each industry as an indicator of innovation/R&D. In turn, they compute the intensity of competition in an industry as follows:

$$c_{jt} = 1 - \frac{1}{N_{jt}} \sum_{i \in j} li_{it}, \tag{31}$$

where N_{jt} is the number of firms in industry j at time t, i indexes firms, and li is the price-cost margin/Learner index. Aghion et al. (2005) compute it as

$$li_{it} = \frac{\text{operating profits - financial costs}}{\text{sales}}. \tag{32}$$

They run a regression of the following form:

$$\mathbb{E}\left[p_{jt} | c_{jt}, x_{jt}\right] = \exp\left(\beta_1 c_{jt} + \beta_2 c_{jt}^2 + x_{jt}'\Gamma\right), \tag{33}$$

where p_{jt} is the citation-weighted number of patents, β_1, β_2 and Γ are parameters and x_{jt}' are control variables. To alleviate reverse causality concerns, Aghion et al. (2005) use the control function approach. They find that $\beta_1 > 0$ and $\beta_2 < 0$ and that the relationship between competition and innovation has an inverted-U shape. In column 1 of Table B, I present their preferred results from column 4 of Table 1 of their paper.[3]

In the main text, I show that competition for factor inputs across two industries can create a link between competition in one industry and innovation in the other. I utilize the 2-digit SIC symmetric input-output table and develop a measure of proximity between industries in terms of factor inputs to formally test this in a setting with multiple industries. From the input-output table, I obtain the share of compensation for each input out of the total input compensation in the 2-digit

SIC industries in the UK in 1984.[4] For each industry, I compute the Euclidean distances between the vector of its input compensation shares and the vectors of input compensation shares of the remainder of industries. The distances of these vectors are a measure of dissimilarity between industries, and I take their inverse to obtain a measure of proximity between industries. Let θ_{jm} be the values of this proximity measure between industries j and m. I replace $\theta_{jj} = 0$ and compute for industry j the interaction between its proximity to other industries and competition in those industries,

$$\hat{c}_{jt} = \sum_m \theta_{jm} c_{mt}. \tag{34}$$

The data used by Aghion et al. (2005) are unbalanced and many (non-overlapping) years are missing for SIC industries 23, 35, 37 and 49. I drop these industries from the sample because keeping them severely restricts the number of observations when computing $\hat{c}_{jt}$. Column 2 of Table B offers the results from the estimation of specification (33) for the restricted sample.

I augment specification (33) with additional terms and estimate the following regression:

$$\mathbb{E}\left[p_{jt} | c_{jt}, x_{jt}\right] = \exp\left(\beta_1 c_{jt} + \beta_2 c_{jt}^2 + \delta_1 \hat{c}_{jt} + \delta_2 \hat{c}_{jt}^2 + x_{jt}' \Gamma\right). \tag{35}$$

According to the theoretical model developed in the main text, the estimate of β_1 is expected to be positive, while that of δ_1 is expected to be negative. It can also be expected that the estimate of β_2 is negative so that the relationship between competition and innovation in an industry has a shape resembling an inverted-U. This is because, in this model, the relationship between competition and innovation in an industry is increasing and concave, as long as there is a positive amount of innovation. Moreover, increasing competition in an industry reduces profits in equation (12) and there is a level of competition at which profits are equal to zero. Innovation increases with competition till this level and ceases when the level of competition increases above this level. In the same vein, the estimate of δ_2 can be expected to be positive since resources that can be devoted to R&D decline with competition in rival industries at a declining rate. This is because of the concave relationship between competition and innovation in an industry. Moreover, they increase in an industry if some of the rival industries stop innovating.

Table B: The Effects of Competition on Innovation

Dependent variable: citation-weighted count of patents in industry j at time t	(1)	(2)	(3)	(4)
c_{jt}	386.592***	246.337***		220.652**
	(67.611)	(93.873)		(95.365)
c_{jt}^2	-205.320***	-127.915***		-114.630**
	(36.105)	(50.346)		(51.124)
$\hat{c}_{jt}$			-104.314***	-72.159*
			(40.486)	(41.811)
$\hat{c}_{jt}^2$			38.222***	26.223*
			(15.185)	(15.736)
Observations	354	286	286	286

Note: This table presents the results from the estimation of specification (35). Column 1 reports the results from column 4 of Table 1 of Aghion et al. (2005). These results can be obtained estimating specification (35) for the full sample of industries and parameter restriction $\delta_1 = \delta_2 = 0$. Column 2 reports the results when I drop SIC industries 23, 35, 37 and 49 from the sample and keep $\delta_1 = \delta_2 = 0$. In columns 3 and 4, SIC industries 23, 35, 37 and 49 are dropped from the sample. Columns 3 and 4 report the results from the estimation of specification (35) with and without parameter restriction $\beta_1 = \beta_2 = 0$, correspondingly. All regressions include industry and year dummies and use the Poisson regression framework. Moreover, all regressions are carried out using the control function method. To implement it, c_{jt} and $\hat{c}_{jt}$ are linearly projected on a set of exogenous instruments (see, for the list of instruments Aghion et al., 2005). The residuals from these projections are added in specification (35) as independent variables. The exogenous instruments are jointly significant in these projections and R-squares are higher than 0.8. Standard errors are reported in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Column 3 of Table B reports the results from the estimation of specification (35) under the restriction $\beta_1 = \beta_2 = 0$. Column 4 of Table B reports the results without this restriction. As expected, the estimate of δ_1 is negative. which suggests that innovation in an industry can decline with higher competition in other and closely related industries. The estimates of β_1, β_2, and δ_2 also have the expected signs.

According to Column 4 of Table B, it is important to control for $\hat{c}$ and $\hat{c}^2$ in (35) for the identification of the magnitude of estimates of β_1 and β_2. These estimates change by about 10 percent when $\hat{c}$ and $\hat{c}^2$ are controlled for.[5]

The results reported in columns 3 and 4 of Table B constitute a first attempt to show that competition in an industry can affect innovation and growth in other industries. They outline an area of potentially fruitful future research.

B.2 Calibration of the Chu (2011) and Goh and Olivier (2002) Models

The model of this paper and the model developed by Chu (2011) feature two horizontally related sectors, whereas the model developed by Goh and Olivier (2002) features two vertically related sectors. Therefore, it is straightforward to calibrate the model of Chu (2011) for the goods and services sectors as it is done in this paper. I discuss the calibration and results for the model of Chu (2011) first because of this. I change the notations of the models of Chu (2011) and Goh and Olivier (2002) to align them more closely with the notation used in this paper.

Chu (2011) considers a two-sector version of the canonical Schumpeterian growth model. In this model, equilibrium labor force allocations to production and R&D in sector k ($k = 1, 2$) are given by

$$L_{x_k} = \sigma_k \left(L + \frac{\rho}{\varphi_1} + \frac{\rho}{\varphi_2} \right) \frac{1}{\mu_k}, \tag{36}$$

$$L_{r_k} = \sigma_k \left(L + \frac{\rho}{\varphi_1} + \frac{\rho}{\varphi_2} \right) \left(\frac{\mu_k - 1}{\mu_k} \right) - \frac{\rho}{\varphi_k}, \tag{37}$$

where σ_k is the share of expenditures on sector k out of expenditures on final consumption goods, ρ is the discount rate, and φ_k is a technological opportunity parameter. A higher value of φ_k increases the arrival rate of innovations. Conceptually, φ_k is similar to ξ_k and γ_k since increasing φ_k increases the sectoral growth rate for a given amount of labor allocated to R&D. In turn, μ_k is the patent breadth parameter. It characterizes the strength of property rights by establishing the minimal difference between an idea and current patents such that the idea can be patented. At the same time, it measures the market power of producers (patent holders) because it defines their power to exclude certain ideas from being patented and produced. It is given by

$$\mu_k = \frac{1}{1 - 1/e_k}. \tag{38}$$

The growth rates of sectors and final output are given by

$$g_k = \varphi_k L_{r_k} \ln z, \tag{39}$$

$$g_C = \sigma_1 g_1 + (1 - \sigma_1) g_2, \tag{40}$$

where z is the exogenous step size of productivity improvement from an innovation.

I calibrate this model for the goods and services sectors. The values of L, ρ, σ_k, and $1/e_k$ are from Table 1. I set z to be equal to the base of the natural logarithm so that $\ln z = 1$ and derive the values of μ_k from equation (38). Finally, I calibrate φ_k using the values of sectoral growth rates. Panel A of Table C offers the values of μ_k and φ_k for $k = 1, 2$, where the goods sector is sector 1 and the services sector is sector 2.

Table D reports the effects of a 10 percent increase in $1/e_k$ in the goods and services sectors on sectoral growth rates, as well as on the growth rate of final output. As a policy, these comparative statics correspond to increasing patent breadth and in that sense they correspond to strengthening property rights in the goods and services sectors in the model of Chu (2011). Sectoral and aggregate growth increase with patent breadth in this model.

These results differ from the results of the model of this paper in a few notable ways. Changes in $1/e_k$ have no cross-sectoral effects in the model of Chu (2011). This is because $1/e_k$ does not affect labor force allocation to sector k in the model of Chu (2011). It affects labor force allocation across production and R&D activities within sector k. This can be clearly seen by summing up L_{x_k} and L_{r_k} from equations

Table C: The Values of Parameters of the Chu (2011) and Goh and Olivier (2002) Models

A. Chu (2011)								
		z	2.718					
		μ_1	μ_2	φ_1	φ_2			
	Germany	1.098	1.298	1.587	0.215			
	UK	1.136	1.163	1.729	0.306			
	US	1.159	1.287	1.231	0.162			
B. Goh and Olivier (2002)								
		1/e						
	Germany	0.162						
	UK	0.132						
	US	0.188						
	χ	0.200	0.300	0.400	0.500	0.600	0.700	0.800
Germany	b_i and b_j	1.737	0.772	0.450	0.290	0.193	0.129	0.083
	A	1.112	0.908	0.851	0.874	0.974	1.189	1.665
	ϵ	5.000	3.333	2.500	2.000	1.667	1.429	1.250
UK	b_i and b_j	1.372	0.610	0.356	0.229	0.152	0.102	0.065
	A	1.267	1.039	0.976	1.005	1.122	1.371	1.920
	ϵ	5.000	3.333	2.500	2.000	1.667	1.429	1.250
US	b_i and b_j	2.088	0.928	0.541	0.348	0.232	0.155	0.099
	A	0.737	0.614	0.587	0.614	0.696	0.863	1.227
	ϵ	5.000	3.333	2.500	2.000	1.667	1.429	1.250

Note: Panel A in this table offers the calibrated values of parameters of the model of Chu (2011). The goods sector is sector 1 and the services sector is sector 2. Panel B offers the calibrated values of parameters of the model of Goh and Olivier (2002). See Table 1 for sample periods, the values of growth rates and the reminder of parameters.

Table D: The Growth Effects of Increasing Patent Breadth in the Chu (2011) Model

	A: 10%Δ in $1/e_1$			B: 10%Δ in $1/e_2$			C: 10%Δ in $1/e_1$ and $1/e_2$		
%Δ in	g_1	g_2	g_C	g_1	g_2	g_C	g_1	g_2	g_C
Germany	16.920	0.000	7.197	0.000	21.338	12.262	16.920	21.338	19.459
UK	15.919	0.000	6.635	0.000	23.272	13.572	15.919	23.272	20.207
US	18.102	0.000	7.132	0.000	27.379	16.591	18.102	27.379	23.724

Note: This table offers the effects of increasing patent breadth (10% increase in $1/e_k$) on labor productivity growth rates in the goods and services sectors (g_1 and g_2) and on the growth rate of the economy $[g_C = \sigma_1 g_1 + (1-\sigma_1)\, g_2]$ in Chu (2011) model. The effects are computed as percentage changes from the values of growth rates offered in Table 1. The goods sector is sector 1 and the services sector is sector 2.

(36) and (37). Moreover, innovation in sector k increases with $1/e_k$ in the model of Chu (2011). Such an inference holds because innovation is carried out by entrants in this model, and increasing $1/e_k$ increases entrants' post innovation profits and value. In contrast, innovation declines with $1/e_k$ in the model of the current paper. This is because increasing $1/e_k$ reduces competition, sales, and the marginal product of innovation.[6]

Goh and Olivier (2002) consider a two-sector version of the Romer (1990) model, where the sectors of the economy are vertically related. In this model, the growth rate of final output is given by

$$g_C = \chi g_i, \tag{41}$$

where g_i is the rate of innovation in the intermediate goods sector,

$$g_i = \frac{A_i \chi b_i \left(L + \frac{\rho}{A_j} + \frac{\rho}{A_i} \right)}{\left(1 + \frac{b_j}{\epsilon - 1} \right) \left(1 + \frac{\chi b_i}{1 - \chi} \right)} - \rho, \tag{42}$$

χ is the share of labor compensation in the final goods sector, ϵ is the elasticity of substitution between final goods, ρ is discount rate, and A_i and A_j are R&D productivity parameters in the R&D labs of the intermediate and final goods sectors.[7] These parameters are conceptually similar to ξ_k and γ_k. In turn, b_i and b_j are patent breadth parameters for the intermediate and final goods sectors. Similarly to Chu (2011), they are related to competition and mark-ups in the corresponding sectors:

$$\frac{\chi b_i}{1-\chi} = \frac{1}{e_i - 1}, \tag{43}$$

$$\frac{b_j}{\epsilon - 1} = \frac{1}{e_j - 1}. \tag{44}$$

To calibrate the values of the model parameters, I assume that mark-ups in the intermediate and final goods sectors are equal and that initially there are no differences between b_i and b_j: $\chi b_i/(1-\chi) = b_j/(\epsilon - 1)$ and $b_i = b_j$. I also assume that $A_i = A_j$ and denote $e \equiv e_i = e_j$.

I compute the price-cost margin at the economy-level, take its average over time and use this average $(1/e)$ to compute the values of $\chi b_i/(1-\chi)$ and $b_j/(\epsilon-1)$. The share of labor compensation in the final goods sector χ is allowed to vary freely in $(0.2, 0.8)$ interval. For a given value of χ, the value of A is computed using the value of g_C from Table 1. Panel B of Table C offers the calibrated values of these parameters.

Table E reports the effects of a 10 percent increase in b_i and b_j on the growth rate of final output. As a policy, this corresponds to increasing the strength of property rights in the intermediate and final goods sectors in the model of Goh and Olivier (2002).

The growth rate of final output increases with the strength of patent breadth in the intermediate goods sector and declines with the strength of patent breadth in the final goods sector. The latter result holds because, similarly to the model of the current paper, competition and property rights regulations have cross-sectoral effects in the model of Goh and Olivier (2002). Within a sector, innovation increases with b and mark-ups in the model of Goh and Olivier (2002).[8] This is similar to the model of Chu (2011) and in contrast to the model of the current paper. Again,

Table E: The Growth Effects of Increasing Patent Breadth in the Goh and Olivier (2002) Model

$\%\Delta$ in g_C	A: $10\%\Delta$ in b_i	B: $10\%\Delta$ in b_j	C: $10\%\Delta$ in b_i and b_j
Germany	12.962	-2.502	10.254
UK	11.435	-2.089	11.435
US	10.748	-3.327	10.748

Note: This table offers the effects of increasing patent breadth (10% increase in b_i and b_j) on the growth rate of the economy in the Goh and Olivier (2002) model. The effects are computed as percentage changes from the value of growth rate offered in Table 1 and are invariant to the value of χ.

such an inference holds because increasing b and mark-ups increases the entrants' post innovation profits and value in the model of Goh and Olivier (2002).

Notes

[1]This derivative is also negative (positive) if $\sigma_1 = 1/2$, $\gamma_1 = \gamma_2$, $\xi_1 = \xi_2$, and $\alpha_{2,1} > \alpha_{1,1}$ ($\alpha_{2,1} < \alpha_{1,1}$). Therefore, the strength of property rights can play an important role for the effect of product market competition in an industry on economic growth.

[2]In the one-sector model developed by Chantrel, Grimaud, and Tournemaine (2012), resource allocation and growth are socially optimal when licensors can verify the use of their patents and have the bargaining power to exclude the use (i.e., $\alpha_{\cdot,2} = 1$). In the current model, this happens only when $e_1 = e_2$.

[3]The authors have recently corrected that table and the corrections are available online.

[4]I use the 1984 input-output tables because the industry classification in this table directly matches with the industry classification used by Aghion et al. (2005). Using a fixed year for shares should not be a major issue because usually the shares of compensations change very little over time.

[5]It has to be noted that these changes are not statistically significant, even though they are economically sizeable.

[6]The previous section of this appendix provides empirical evidence that competition can have cross-sector effects. In turn, Blundell, Griffith, and van Reenen (1999) provide evidence that innovation increases with competition. The model of this paper can also generate an inverted-U shape like relationship between competition and innovation (Aghion et al., 2005).

[7]I consider the case when both the final and intermediate input sectors innovate.

[8]The rate of innovation in the final goods sector is given by $g_j = [A_j \frac{b_j}{\epsilon - 1}(L + \frac{\rho}{A_j} + \frac{\rho}{A_i})/(1 + \frac{b_j}{\epsilon - 1})] - \rho$.

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