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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 of the other sector. The overall impact of such policies on economic growth is ambiguous because of this. I perform a numerical exercise in an attempt of resolving the ambiguity. This exercise suggests that strengthening intellectual property rights can increase economic growth, but higher competition has a very limited effect on growth.

JEL Codes: O31, O34, L16,L50, O41.

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

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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). Studies in industrial organization consider the effects of such regulations in partial equilibrium frameworks. A large number of recent studies 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., Judd, 1985, Smulders and van de Klundert, 1995, Yang and Maskus, 2001, O'Donoghue and Zweimüller, 2004, Chu and Pan, 2013).

These studies have delivered 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 another sector. Considering sectoral heterogeneity can be important because, for example, the regulation of intellectual property has been historically different across goods and services sectors. Patents on software and business methods are relatively recent phenomena and have proved to be very relevant to, in particular, 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 product line and can engage in in-house R&D, which then drives long-run growth. In a

[1] The division of an economy into services and goods sectors has not been very popular in studies of innovation and growth because services have been usually thought to have very 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 starting from the 90s.

firm, innovation enhances firm-specific knowledge on the process of production (alternatively, it enhances the knowledge for the quality of the firms' product). This knowledge is patented. The firms compete strategically in the output market and finance their R&D expenditures from operating profits. In-house R&D process builds on the knowledge that the firms possess. In a firm, the R&D process can be improved combining 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 precisely, 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. 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 extent of appropriated returns on R&D and higher competition increases sales and, as a consequence, it increases the marginal product of innovation. However, these policies adversely affect R&D investments in the other sector. R&D investments in the other sector decline because of an 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 the negative effect of these regulations on R&D investments and growth of the other sector. For example, a split of the economy into goods and services sectors, which is common in aggregate-level studies, would not help to resolve the ambiguity because these positive and negative effects are not straightforward to identify. I make a step toward better informed long-run policy implications from the model and perform a simple calibration exercise for 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 property rights in goods and services sectors. Such results hold when property rights are strengthened in one of these 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 these 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 these papers, R&D in a firm improves the production process (or the quality) of a good and is performed in-house by the firm in the current paper. This modeling choice is motivated by an observation that large, incumbent firms are responsible for sizeable portions of R&D, patenting and cross-licensing activities. Moreover, in the model of this paper, the regulation of intellectual property is distinct from product market regulation. The regulation of intellectual property affects the bargaining power of firms in the market for patents/knowledge.[2] This paper also

[2]The interaction of Apple Inc, Google, and Microsoft in product and patent markets provides a seemingly appropriate example motivating such a separation. These firms are rivals in product markets and have

performs a simple quantitative analysis for goods and services sectors.

Having a focus on long-run growth, the analysis of this paper omits potential welfare effects of regulations of intellectual property and product market competition. 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 (2015) offer a detailed account of 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 not likely to affect it.[3]

The results of this paper also have implications for 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 offers the results from the model and a simple calibration exercise. Section 4 concludes. The proofs of the results are offered at the end of the paper.

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

varying degrees of bargaining power in licensing agreements.

[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 can be quite limited.

the future streams of utility with rate ρ. The utility gains are from the consumption of amount C of consumption goods. The lifetime utility of the household is given by

$$U = \int_0^{+\infty} \ln C_t \exp(-\rho t)\, dt.$$

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

$$\dot{A} = rA + wL - C, \tag{1}$$

where A are the household's asset holdings $[A(0) > 0]$, r and w are the market returns on its asset holdings and labor supply.

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

$$\frac{\dot{C}}{C} = r - \rho. \tag{2}$$

This equation, together with the budget constraint (1), 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

$$C = X_1^{\sigma_1} X_2^{\sigma_2}, \tag{3}$$

where

$$X_k = \left(\sum_{j=1}^{N_k} x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}} \right)^{\frac{\varepsilon_k}{\varepsilon_k - 1}}, \tag{4}$$

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:

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

$$s.t.$$

$$(3), (4),$$

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

$$p_{x_{k,j}} x_{k,j} = \sigma_k C \frac{x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}}{\sum_{j=1}^{N_k} x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}}. \tag{5}$$

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

$$x_{k,j} = \lambda_{k,j}^{\gamma_k} L_{x_{k,j}}, \tag{6}$$

where $L_{x_{k,j}}$ is its labor input, $\lambda_{k,j}$ measures its productivity (or the quality of its product), and $\gamma_k \in (0, 1]$. 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-house R&D, which allows them to improve their productivity. They hire labor 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 a new one. Within a sector, the firms can licence knowledge/patents from each other. There are also knowledge spillovers among the firms and the firms obtain some knowledge without compensation/for free. The knowledge production technology of the firm j from sector k is given by

$$\dot{\lambda}_{k,j} = \xi_k \left[\sum_{i=1}^{N_k} \bar{\lambda}_{k,i}^{\alpha_{k,1}} \left(u_{k,j,i}\lambda_{k,i}\right)^{\alpha_{k,2}} \right] \lambda_{k,j}^{1-\tilde{\alpha}_k} L_{r_{k,j}}, \tag{7}$$
$$\alpha_{k,1}, \alpha_{k,2} > 0; \tilde{\alpha}_k = \alpha_{k,1} + \alpha_{k,2}; \tilde{\alpha}_k < 1,$$

where ξ_k is an exogenous productivity level, $u_{k,j,i}$ is the share of knowledge that the firm j licenses/purchases from a firm i, $\lambda_{k,i}$, and $u_{k,j,j} \equiv 1$. The term $\bar{\lambda}_k$ represents the spillovers of knowledge among firms in sector k. In turn, I assume that $\alpha_{k,1} > 0$, $\alpha_{k,2} > 0$ and $\alpha_{k,1} + \alpha_{k,2} < 1$ 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 compensations 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 the firm j is given by

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

$s.t.$

$(5), (6), (7),$

where t is the entry date,

$$\pi_{k,j} = p_{x_{k,j}} x_{k,j} - w\left(L_{x_{k,j}} + L_{r_{k,j}}\right) + \left[\sum_{i=1, i\neq j}^{N_k} p_{\lambda_{k,j}} \left(u_{k,i,j}\lambda_{k,j}\right) - \sum_{i=1, i\neq j}^{N_k} p_{\lambda_{k,i}} \left(u_{k,j,i}\lambda_{k,i}\right) \right], \tag{8}$$

and $p_{\lambda_{k,j}}$ and $p_{\lambda_{k,i}}$ are the license fees for $u_{k,j,i}$ and $u_{k,i,j}$ shares of $\lambda_{k,j}$ and $\lambda_{k,i}$ patent portfolios.[4]

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

$$w = \left(1 - \frac{1}{e_{k,j}}\right) p_{x_{k,j}} \frac{x_{k,j}}{L_{x_{k,j}}}, \tag{9}$$

$$w = q_{\lambda_{k,j}} \frac{\dot{\lambda}_{k,j}}{L_{r_{k,j}}}, \tag{10}$$

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 Bertrand competition it is given by

$$e_{k,j} = \varepsilon_k - \left[\frac{(\varepsilon_k - 1)\, p_{x_{k,j}}^{1-\varepsilon_k}}{\sum_{j=1}^{N_k} p_{x_{k,j}}^{1-\varepsilon_k}} \right], \tag{11}$$

and under Cournot competition it is given by

$$e_{k,j} = \varepsilon_k \left\{ 1 + \left[(\varepsilon_k - 1) \frac{x_{i,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}}{\sum_{j=1}^{N_k} x_{k,j}^{\frac{\varepsilon_k - 1}{\varepsilon_k}}} \right] \right\}^{-1}. \tag{12}$$

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

$$u_{k,i,j} = 1, \tag{13}$$

$$p_{\lambda_{k,i}} = q_{\lambda_{k,j}} \alpha_{k,2} \xi_k \frac{\left[\bar{\lambda}_k \left(u_{k,j,i}\lambda_{k,i}\right)^{\alpha_{k,2}}\right] \lambda_{k,j}^{1-\alpha_{k,1}-\alpha_{k,2}}}{u_{k,j,i}\lambda_{k,i}} L_{r_{k,j}}, \tag{14}$$

[4] The results of this paper depend on the assumption that the same type of labor is employed in production and R&D in both industries. This is not an uncommon assumption and is maintained, for example, by Klenow (1996) and Goh and Olivier (2002).

and

$$\frac{\dot{q}_{\lambda_{k,j}}}{q_{\lambda_{k,j}}} = r - \left(\gamma_k \frac{e_{k,j}-1}{e_{k,j}} \frac{p_{x_{k,j}}}{q_{\lambda_{k,j}}} \frac{x_{k,j}}{\lambda_{k,j}} + \sum_{i=1, i\neq j}^{N_k} \frac{p_{\lambda_{k,j}}}{q_{\lambda_{k,j}}} u_{k,i,j} + \frac{\partial \dot{\lambda}_{k,j}}{\partial \lambda_{k,j}} \right), \tag{15}$$

where

$$\frac{\partial \dot{\lambda}_{k,j}}{\partial \lambda_{k,j}} = \xi_k \bar{\lambda}_k L_{r_{k,j}} \times \left\{ \alpha_{k,2} \lambda_{k,j}^{-\alpha_{k,1}} + (1-\alpha_{k,1}-\alpha_{k,2}) \left[\sum_{i=1}^{N_k} (u_{k,j,i}\lambda_{k,i})^{\alpha_{k,2}} \right] \lambda_{k,j}^{-\alpha_{k,1}-\alpha_{k,2}} \right\}. \tag{16}$$

Firms license the entire portfolio of their patents/knowledge according to (13). They do so because there are no costs associated with licensing and there are no strategic considerations in the market for knowledge.[5] In turn, firms are willing to pay a positive fee for licensing knowledge according to (14) 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 are proportional to the average level of knowledge in the economy and are given by

$$\bar{\lambda}_k = \frac{1}{N_k} \sum_{j=1}^{N_k} \lambda_{k,j}, \tag{17}$$

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

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, reducing $\alpha_{k,1}$ and increasing $\alpha_{k,2}$. Reducing $\alpha_{k,1}$ and increasing $\alpha_{k,2}$ increases the compensation of licensors and firms' returns on knowledge accumulation and reduces free-riding according to (14) and (15). In this sense, $\alpha_{k,1}$ represents the inverse of the strength of intellectual property rights in this framework.

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

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.

Several modeling choices deserve a detailed discussion. The R&D process in (7) does not allow 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, usually patent licensing is quite rare across broad sectors as compared to patent licensing within sectors (see, for a similar assumption, Goh and Olivier, 2002, Chu, 2011). The specification of knowledge spillovers process (17), together with the R&D process, has the attractive property of allowing the model to have a well defined balanced growth path.[6] Moreover, the market for patents/knowledge can be thought to be organized in terms of a Nash-bargaining game between licensees and licensors because of this specification of knowledge spillovers. In this respect, the parameter $\alpha_{k,1}$ can be thought to represent the bargaining power of licensees because increasing it reduces $\alpha_{k,2}$ and the compensation of licensors according to (14). The property rights system then affects the bargaining power of the participants in the market for knowledge. For example, it affects the process and settlements in patent litigations (see, for further discussion of this R&D process, Jerbashian, 2016).

3 Features of the Equilibrium

I focus on a symmetric equilibrium within intermediate goods sectors. The results pertain to long-run growth and are carried for balanced growth path.

[6] Similar to the models of Goh and Olivier (2002) and Chu (2011), there are scale effects in this model. These effects are contentious (Jones, 1995, Jones and Romer, 2010), and Jerbashian (2016) shows how to eliminate them in a one sector model, while keeping the inference for knowledge licensing intact. I prefer the current specification because of its analytical versatility.

In a symmetric equilibrium, from (5) and (9) it follows that

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{18}$$

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

$$D = \frac{1-\sigma_1}{\sigma_1} \frac{e_1}{e_1 - 1} \frac{e_2 - 1}{e_2}. \tag{19}$$

The relation between $N_2 L_{x_2}$ and $N_1 L_{x_1}$ in (18) 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 (18), $N_2 L_{x_2}$ increases (declines) 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 (18) and labor market clearing condition,

$$L = \sum_{k=1}^{2} \left(N_k L_{x_k} + N_k L_{r_k} \right), \tag{20}$$

gives a relation between production inputs in sector 1 and R&D inputs in sectors 1 and 2:

$$N_1 L_{x_1} = (1 + D)^{-1} \left(L - \sum_{k=1}^{2} N_k L_{r_k} \right). \tag{21}$$

The returns on knowledge accumulation in sector k can be derived from (7), (9), (10), (14), (13), (15), (16) and (17). They are given by

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

Combining this relation with (2), (4), (6), (9), and (10) gives

$$0 = \rho - \frac{\dot{\lambda}_k}{\lambda_k} \left(\frac{N_k L_{x_k}}{N_k L_{r_k}} - \alpha_{k,1} \right). \tag{22}$$

Labor allocations in sectors can be derived combining (7), (18), (21), and (22).

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

$$N_1 L_{x_1} = \frac{\xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} \frac{\alpha_{2,1}}{\gamma_2} L + \left(\xi_2 \frac{\alpha_{2,1}}{\gamma_2} \frac{1}{\gamma_1} + \xi_1 \frac{\alpha_{1,1}}{\gamma_1} \frac{1}{\gamma_2} \right) \rho}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1 + D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}, \tag{23}$$

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{24}$$

and

$$N_1 L_{r_1} = \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2} (1 + D) + D \right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1 + D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}, \tag{25}$$

$$N_2 L_{r_2} = \frac{D \xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} L - \xi_1 \left[\frac{\alpha_{1,1}}{\gamma_1} (1 + D) + 1 \right] \frac{\rho}{\gamma_2} + \xi_2 D \frac{\rho}{\gamma_1}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1 + D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}. \tag{26}$$

The growth rates in sectors are proportional to the resources invested in R&D and can be derived from (6), (7), (25) and (26). In turn, the growth rate of consumption goods (final output) is given by

$$g_C = \sigma_1 \gamma_1 g_{\lambda_1} + (1 - \sigma_1) \gamma_2 g_{\lambda_2}, \tag{27}$$

where I use letter g to denote growth rates. This is a straightforward relation and states that the growth rate of the economy is a weighted average of sectoral growth rates.

The exponent of the firms' own knowledge in the R&D process, $1 - \tilde{\alpha}_k$, does not explicitly appear in equilibrium conditions (23)-(26) because R&D process is homogenous of degree 1 in knowledge. This is also the reason why $\alpha_{k,2}$ does not appear in these equilibrium conditions since the value of $\alpha_{k,2}$ is uniquely determined for the given values of $\tilde{\alpha}_k$ and $\alpha_{k,1}$. Nevertheless, the value of $\tilde{\alpha}_k$ imposes restrictions on 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 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 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 output 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.[7] 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 competition in a sector reduces its prices relative to the prices of the rival sector and increases its output. This reduces the output of the rival sector according to (18), its revenues and the marginal product of innovation. Therefore, it reduces innovation and growth in the rival sector. In turn, stronger property rights in a sector increase its demand for R&D investments. 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. The higher wage rates are also the reason for the third part of the results in this corollary, they drain resources for production from both sectors.

[7] It can be shown that increasing competition reduces profits in (8) 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).

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 in (27) is ambiguous. It depends on 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 of the other sector.[8] (The Technical Appendix offers formal proves for these statements).

These results suggest that it is ultimately an empirical question whether uniform changes in intellectual property and competition regulations can increase long-run growth. Similarly, it is an empirical question 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 model parameters in the next section.

Quantitative Exercise

The model features expenditures on and income from patent licensing. Currently, there are no comprehensive data for these and R&D expenditures might be contaminated by expenditures on licensing. I take a sufficiently broad view of model variables to be able to match them with the available data. In this sense, the calibration exercise presented in this section is a first step toward parameterizing the model for a more informed policy discussion.

I obtain data for the calibration exercise from the EU KLEMS database. The data are at yearly frequency and are for Germany, the UK, and the US. Table 1 offers sample period for each country.

I split these economies into goods and services sectors according to 1-digit ISIC (Rev. 3) code and compute the value added share of goods sector out of total value added.

[8] 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.

This share has declined over time everywhere. I set σ_1 to be equal to this share in sample countries in 2007, which is the last year in 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, which are the empirical analogues of markups $1/e_k$. Price-cost margin is defined as the ratio of the difference between output and labor and intermediate costs and output.[9] I take the average of price-cost margins over 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 (22) to calibrate the values of $\alpha_{k,1}$. This equation can be rewritten in the following way:

$$\alpha_{k,1} = \left[\left(1 - \frac{1}{e_k}\right)\frac{N_k p_{x_k} x_k}{N_k w L_{r_k}} - \frac{\rho}{g_k}\right]\gamma_k, \tag{28}$$

where the first term in the 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. I compute the ratios of value added and investments in goods and services sectors in sample countries and take the averages of these ratios over 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 goods and services sectors in sample countries.

The values of ξ_1 and ξ_2 can be obtained from equations (25) and (26) for given values of $\alpha_{k,1}$ and γ_k. Similarly to the equation for $\alpha_{k,1}$ (28), I rewrite these equations to have labor productivity growth rates:

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

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

According to (6) and (7), ξ_k and γ_k jointly identify the effect of a marginal increase

[9] Griffith, Harrison, and Simpson (2010) and Jerbashian and Kochanova (2017) compute markups in a very similar way.

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 because of 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 (28), $\alpha_{k,1}$ 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.

Admittedly, this calibration strategy is not without trade-offs and limitations. First, the use of general investments can obscure the interpretation of $\alpha_{k,1}$. Nevertheless, I prefer using general investments since they can be directly linked to broad measures of growth such as the growth rate of labor productivity. They also tend to be readily available and easily measured, at least from the perspective of this paper. Second, I use equilibrium conditions to pin down the values of model parameters, which might be problematic because this small model might not be a very accurate description of the real economy. Fortunately, at least (28) does not use the entire general equilibrium structure of the model. The model then serves the useful purpose of providing a structural interpretation for $\alpha_{k,1}$. Third, in this calibration, I assume that the growth rate of labor productivity is entirely driven by R&D (investments). Comin (2004) argues that the contribution of R&D to growth is not very large. In this respect, the quantitative results of this paper correspond to the effects of intellectual property and product market regulations on the contribution of R&D to growth.

Table 1 summarizes the values of model parameters for the sample countries and goods and services sectors. It also offers labor productivity growth rates in goods and services sectors, g_k, and the values of g_C, which is a weighted average of labor productivity growth rates in these sectors and is given by (27). To maintain the notation, goods sector is sector 1 and services sector is sector 2.

A seemingly reassuring result about the values of these parameters is that spillovers in goods sector are lower in the US than in Germany and the UK. This could be because the protection of intellectual property in goods sector is stronger in the US than in

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

L	1.000							
rho	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 model parameters. It also offers 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. Goods sector is sector 1 and services sector is sector 2. Goods sector is comprised of A, B, C, D, E, and F 1-digit ISIC industries, and services sector is comprised of the remainder of 1-digit ISIC industries.

European countries. As compared to 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 the spillovers in goods sector. The evident similarity among Germany, the UK and the US could be because of similar levels of patent protection of business methods and software innovations, which is relatively common in services sector and is a recent phenomenon. However, the difference between the levels of spillovers in goods and services sectors might not be so straightforward to attribute solely to the differences in the protection of intellectual property. For example, differences in the levels of tacit knowledge in goods and services sectors can also contribute to the differences between the levels of spillovers. In the model, such differences emerge when the exponent of the firms' own knowledge in the R&D process, $1-\tilde{\alpha}_k$, in the goods sector is lower than in the services sector. This imposes a stricter restriction on the values of $\alpha_{k,1}$ from above in the goods goods sector than in the services sector.

The values of the markups also seem to fall in a reasonable ballpark. They are very close to the values used by, for example, 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 services and goods 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 (7), this is given by

$$g_k / N_k L_{r_k} = \gamma \xi_k. \tag{29}$$

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 through this exercise and through calibration turn out to be surprisingly small.

Table 2: Calibrated Values of $\gamma\xi_1$ and $\gamma\xi_2$ and their Values Implied by (29)

	$\gamma\xi_1$		$\gamma\xi_2$	
	Calibrated	Implied by (29)	Calibrated	Implied by (29)
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 (29) 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 services and goods 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.

I conduct several counterfactual exercises. First, I examine the effect of 10 percent reduction in $\alpha_{k,1}$ in 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 and A.2 of Table 3 summarize the results in terms of percentage changes of 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 rather limited and the growth rate of total output increases with stronger property rights in both sectors. The elasticity of the growth rate and innovation in a sector 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 higher weight in final output. The highest increase in the growth rate of total output can be obtained increasing the strength of property rights in both sectors. According to Panel A.3 of Table 3, 10 percent reduction of $\alpha_{1,1}$ and $\alpha_{2,1}$ increases the growth rate of total output by about 8 percent in sample countries.

I also examine the effect of 10 percent reduction of markups, $1/e_k$, in goods and services sectors. Panels B.1 and B.2 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 quite comparable and the growth rate of total output is almost not affected by stronger competition in either of the sectors. It slightly increases with higher competition in the goods sector and declines with higher competition in the services sector. These result can be important at least for two reasons. They suggest that the aggregate effects of increasing competition in goods sector and/or services sector on long-run growth can be rather limited. 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)

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 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 from the values of growth rates offered in Table 1. Goods sector is sector 1 and services sector is sector 2.

show that, indeed, a higher level of competition in services sector increases welfare in European countries. These papers do not incorporate sector-level R&D in their models, and my results suggest that that is not a significant omission at least from the perspective of long-run growth. Moreover, these results suggest that it is important to control for competition in the remainder of the economy (or in closely related industries) in studies of the impact of competition on innovation and long-run growth in an industry/a sector (e.g., Blundell et al., 1999, Aghion et al., 2005).[10]

In Panel C of Table 3, I also examine the effect of 10 percent increase in the strength of property rights and product market competition in both sectors. The results from this

[10]In the Empirical Appendix, 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.

exercise are similar to those for 10 percent increase in the strength of property rights. This holds because increasing the level of product market competition has rather limited effect on sectoral growth rates.[11]

The effect of increasing product market competition in a sector on the growth rate of the sector is limited because increasing competition entails two and 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 which 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. On the other hand, the effect of strengthening the property rights in a sector on the growth rate of the sector is larger than the effect of increasing product market competition because 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 product market can be correlated because, for example, stronger property rights in a sector can restrict entry into the sector. The comparison of the values of markups and $\alpha_{1,1}$ in the US with these values in Germany and the UK can provide evidence for such a pattern. According to the values of $\alpha_{1,1}$, property rights in goods sector are stronger in the US than in Germany and the UK, where these are of the same order of magnitude. Meanwhile, the level of competition in goods sector is lower in the US than in Germany and the UK according to the values of $1/e_1$. 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 assumes US values of markups and $\alpha_{k,1}$ for Germany and the UK. The growth

[11] Table 4 in the Empirical Appendix 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.

rate of final output in Germany and the UK increases when these countries have the same level of property rights and competition in 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 almost not affected by the level of competition.

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 which 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 simplistic calibration exercise for goods and services sectors in Germany, the UK, and the US. The results from this exercise suggest that stronger property rights in 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 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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5 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 $\left\{p_{\lambda_{k,j}}, p_{\lambda_{k,i}}\right\}_{j,i=1(j\neq i)}^{N_k}$ and the current value of $\lambda_{k,j}$.
  - It chooses $\left\{L_{x_{k,j}}, L_{r_{k,j}}\right\}_{j=1}^{N_k}$ and $\left\{u_{k,i,j}, u_{k,j,i}\right\}_{j,i=1(j\neq i)}^{N_k}$ 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 $\left\{u_{k,i,j}, u_{k,j,i}\right\}_{j,i=1(j\neq i)}^{N_k}$ subject to the demand for its product under Bertrand competition.
- Labor market clears:

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

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

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

- 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 (5) and (9) to obtain a relation between labor force allocations in sectors 1 and 2 in a symmetric equilibrium in these sectors:

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{30}$$

where D is given by (19). This relation, together with the labor market clearing condition,

$$L = \sum_{k=1}^{2} \left(N_k L_{x_k} + N_k L_{r_k} \right), \tag{31}$$

implies that labor force allocations to production in sectors 1 and 2 are given by

$$N_1 L_{x_1} = (1 + D)^{-1} \left(L - \sum_{k=1}^{2} N_k L_{r_k} \right), \tag{32}$$

$$N_2 L_{x_2} = D \left(1 + D\right)^{-1} \left(L - \sum_{k=1}^{2} N_k L_{r_k} \right). \tag{33}$$

All variables grow at constant rates on a balanced growth path. From (7), (32), and (33), it follows that labor allocations are constant on that path.

I use equations (7), (9), (10), (14), (13), (16), and (17) to rewrite (15) in the following way:

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

From the Euler equation (2) and (9), (10), (5), it follows that another equation for the returns on knowledge accumulation is

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

I combine these two equations to obtain

$$0 = \rho - \frac{\dot{\lambda}_k}{\lambda_k} \left(\gamma_k \frac{N_k L_{x_k}}{N_k L_{r_k}} - \alpha_{k,1} \right). \tag{34}$$

This expression, together with (7), (32) and (33), determines labor force allocations in balanced growth path equilibrium. The labor force allocations are given by

$$N_1 L_{x_1} = \frac{\xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} \frac{\alpha_{2,1}}{\gamma_2} L + \left(\xi_2 \frac{\alpha_{2,1}}{\gamma_2} \frac{1}{\gamma_1} + \xi_1 \frac{\alpha_{1,1}}{\gamma_1} \frac{1}{\gamma_2} \right) \rho}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}, \tag{35}$$

$$N_2 L_{x_2} = D N_1 L_{x_1}, \tag{36}$$

and

$$N_1 L_{r_1} = \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}, \tag{37}$$

$$N_2 L_{r_2} = \frac{D \xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} L - \xi_1 \left[\frac{\alpha_{1,1}}{\gamma_1} (1+D) + 1 \right] \frac{\rho}{\gamma_2} + \xi_2 D \frac{\rho}{\gamma_1}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}}. \tag{38}$$

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 balanced growth path equilibrium.

In order to obtain equation (28), I use (34) and the fact that labor productivity growth in sector k is given by

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

where g denotes growth rate.

Proof of Corollary 1

The growth rate of λ_k can be derived from (7):

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

where $N_1 L_{r_1}$ and $N_2 L_{r_2}$ are given by (37) and (38).

Using (35)-(38), it can be shown that

$$\frac{\partial}{\partial D} N_1 L_{x_1} = -\frac{\xi_1\xi_2 \frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2} L + \xi_1 \frac{\alpha_{1,1}}{\gamma_1}\frac{\rho}{\gamma_2} + \xi_2 \frac{\alpha_{2,1}}{\gamma_2}\frac{\rho}{\gamma_1}}{\xi_1\xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} \frac{\alpha_{1,1}}{\gamma_1} \left(\frac{\alpha_{2,1}}{\gamma_2} + 1 \right) < 0, \quad (39)$$

$$\frac{\partial}{\partial D} N_1 L_{r_1} = -\frac{\xi_1\xi_2 \frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2} L + \xi_1 \frac{\alpha_{1,1}}{\gamma_1}\frac{\rho}{\gamma_2} + \xi_2 \frac{\rho}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}}{\xi_1\xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} \left(\frac{\alpha_{2,1}}{\gamma_2} + 1 \right) < 0, \quad (40)$$

and

$$\frac{\partial}{\partial D} N_2 L_{x_2} = \frac{\xi_1\xi_2 \frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2} L + \xi_1 \frac{\alpha_{1,1}}{\gamma_1}\frac{\rho}{\gamma_2} + \xi_2 \frac{\alpha_{2,1}}{\gamma_2}\frac{\rho}{\gamma_1}}{\xi_1\xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} \frac{\alpha_{2,1}}{\gamma_2} \left(\frac{\alpha_{1,1}}{\gamma_1} + 1 \right) > 0, \quad (41)$$

$$\frac{\partial}{\partial D} N_2 L_{r_2} = \frac{\xi_1\xi_2 \frac{\alpha_{1,1}}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2} L + \xi_1 \frac{\alpha_{1,1}}{\gamma_1}\frac{\rho}{\gamma_2} + \xi_2 \frac{\rho}{\gamma_1}\frac{\alpha_{2,1}}{\gamma_2}}{\xi_1\xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} \left(\frac{\alpha_{1,1}}{\gamma_1} + 1 \right) > 0. \quad (42)$$

According to (19), 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 of competition in both sectors can either increase or reduce D depending on the values of e_1 and e_2. Let $\mathbf{e} = (e_1, e_2)$,

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

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.

The partial derivative of the growth rate of consumption goods (final output) with respect to D can be derived from (3), (4), (6), (40), and (42). It is given by

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

The sign of this expression depends on the values of 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 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 $\xi_1 > \xi_2$ ($\xi_1 < \xi_2$).[12]

The partial derivatives of labor force allocations with respect to $\alpha_{k,1}$ can be readily derived from (35)-(38). The partial derivatives with respect to $\alpha_{1,1}$ are given by

$$\frac{\partial}{\partial \alpha_{1,1}} N_1 L_{x_1} = \frac{\alpha_{2,1}}{\gamma_2} \frac{1}{\gamma_1} \frac{\xi_1 \xi_2 L \frac{\alpha_{2,1}}{\gamma_2} - \left\{ \xi_2 \frac{1}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] - \xi_1 \frac{1}{\gamma_2} \right\} \rho}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} > 0, \tag{43}$$

$$\frac{\partial}{\partial \alpha_{1,1}} N_1 L_{r_1} = - \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} \frac{1}{\gamma_1} \tag{44}$$

$$\times \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] < 0, \tag{45}$$

and

$$\frac{\partial}{\partial \alpha_{1,1}} N_2 L_{x_2} = D \frac{\alpha_{2,1}}{\gamma_2} \frac{1}{\gamma_1} \frac{\xi_1 \xi_2 L \frac{\alpha_{2,1}}{\gamma_2} - \left\{ \xi_2 \frac{1}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] - \xi_1 \frac{1}{\gamma_2} \right\} \rho}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} > 0, \tag{46}$$

$$\frac{\partial}{\partial \alpha_{1,1}} N_2 L_{r_2} = \frac{1}{\gamma_1} D \frac{\xi_1 \xi_2 \frac{\alpha_{2,1}}{\gamma_2} L - \xi_2 \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] \frac{\rho}{\gamma_1} + \xi_1 \frac{\rho}{\gamma_2}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} > 0. \tag{47}$$

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

$$\frac{\partial}{\partial \alpha_{2,1}} N_1 L_{x_1} = \frac{1}{\gamma_2} \frac{\alpha_{1,1}}{\gamma_1} \frac{D \xi_1 \xi_2 \frac{\alpha_{1,1}}{\gamma_1} L - \xi_1 \left[\frac{\alpha_{1,1}}{\gamma_1} (1+D) + 1 \right] \frac{\rho}{\gamma_2} + \xi_2 D \frac{\rho}{\gamma_1}}{\xi_1 \xi_2 \left\{ \frac{\alpha_{1,1}}{\gamma_1} \left[\frac{\alpha_{2,1}}{\gamma_2} (1+D) + D \right] + \frac{\alpha_{2,1}}{\gamma_2} \right\}^2} > 0, \tag{48}$$

[12] 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.

$$\frac{\partial}{\partial\alpha_{2,1}}N_1L_{r_1} = \frac{1}{\gamma_2}\frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2} + \xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} > 0. \tag{49}$$

and

$$\frac{\partial}{\partial\alpha_{2,1}}N_2L_{x_2} = D\frac{1}{\gamma_2}\frac{\alpha_{1,1}}{\gamma_1}\frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2} + \xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} > 0, \tag{50}$$

$$\frac{\partial}{\partial\alpha_{2,1}}N_2L_{r_2} = -\frac{D\xi_1\xi_2\frac{\alpha_{1,1}}{\gamma_1}L - \xi_1\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right]\frac{\rho}{\gamma_2} + \xi_2 D\frac{\rho}{\gamma_1}}{\xi_1\xi_2\left\{\frac{\alpha_{1,1}}{\gamma_1}\left[\frac{\alpha_{2,1}}{\gamma_2}(1+D)+D\right]+\frac{\alpha_{2,1}}{\gamma_2}\right\}^2} \tag{51}$$

$$\times\frac{1}{\gamma_2}\left[\frac{\alpha_{1,1}}{\gamma_1}(1+D)+1\right] < 0. \tag{52}$$

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 of $\alpha_{1,1}$ and $\alpha_{2,1}$ on the growth rate in sector k is given by the sum of the partial derivatives of $N_kL_{r_k}$ with respect to $\alpha_{1,1}$ and $\alpha_{2,1}$. The sign and the magnitude of this effect depend on 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 (3), (4), (6), and (43)-(52). They are given by

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

and

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

The signs of these expressions depend on the values of model parameters. This means that the effects of changing $\alpha_{1,1}$ and $\alpha_{2,1}$ on long-run growth depend on 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 of $\alpha_{1,1}$ 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 model parameters.

6 Empirical Appendix

6.1 Further Results

Table 4: 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 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 from the values of growth rates offered in Table 1. Goods sector is sector 1 and services sector is sector 2.

6.2 An Extension of Aghion et al. (2005)

In this section, I use the data and an extension of the empirical methodology of 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 17 SIC 2-digit manufacturing industries and the period of 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 in the following way:

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

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

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

They run a regression of the following form

$$\mathbb{E}\left[p_{jt} | c_{jt}, x_{jt}\right] = \exp\left(\beta_1 c_{jt} + \beta_2 c_{jt}^2 + x_{jt}'\Gamma\right), \tag{53}$$

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 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 5, I present their preferred results from column 4 of Table 1 of their paper (see also a recent correction of that table).

In the main text, I show that competition for factor inputs across two industries can create a link between competition in an industry and innovation in the other industry. I utilize 2-digit SIC symmetric input-output table and develop a measure of proximity among industries in terms of factor inputs to formally test this in a setting with multiple industries. From the input-output table, I obtain the shares of compensations of each input out of total input compensation in 2-digit SIC industries in the UK in 1984.[13] For each industry, I compute the Euclidian distances among the vector of its input compen-

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

sation shares and the vectors of input compensation shares of the remainder of industries. The distances of these vectors are a measure of dissimilarity among 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,

$$\hat{c}_{jt} = \sum_{m} \theta_{jm} c_{mt}.$$

The data of Aghion et al. (2005) is 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 5 offers the results from the estimation of specification (53) for the restricted sample.

I augment (53) with additional terms and estimate the following regression

$$\mathbb{E}\left[p_{jt} | c_{jt}, x_{jt}\right] = \exp\left(\beta_1 c_{jt} + \beta_2 c_{jt}^2 + \delta_1 \hat{c}_{jt} + \delta_2 \hat{c}_{jt}^2 + x_{jt}' \Gamma\right). \tag{54}$$

According to the theoretical model developed in the main text, the estimate of β_1 is expected to be positive and the estimate of δ_1 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 (8) 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. In the same vein, the estimate of δ_2 can be expected to be positive since resources which 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.

Column 3 of Table 5 reports the results from the estimation of specification (54) under the restriction $\beta_1 = \beta_2 = 0$. Column 4 of Table 5 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 5, it is important to control for $\hat{c}$ and $\hat{c}^2$ in (54) 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.[14]

Table 5: 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 (54). Column 1 reports the results from column 4 of Table 1 of Aghion et al. (2005). These results can be obtained estimating (54) for the full sample of industries and under parameter restriction $\delta_1 = \delta_2 = 0$. Column 2 reports the results when I drop from the sample SIC industries 23, 35, 37 and 49 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 (54) 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 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 insruments, Aghion et al., 2005). The residuals from these projections are added in (54) 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.

The results reported in columns 3 and 4 of Table 5 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.

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