The London School of Economics and Political Science

Essays in Innovation and Productivity

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Declaration

I certify that the thesis I have presented for examination for the Ph.D. degree of the London School of Economics and Political Science is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

I warrant that this authorisation does not, to the best of my belief, infringe the rights of any third party.

I declare that my thesis consists of 36,870 words.

Statement of inclusion of previous work

I can confirm that Chapter 3 was the result of a previous study (for the MRes in Economics award) I undertook at the London School of Economics and Political Science.

Abstract

This thesis aims to understand the interplay between innovation, productivity, and market dynamics. Comprising three distinct chapters, the thesis analyzes various aspects of innovation behaviour, productivity and its implications.

This first chapter attempts to understand the relationship between worker productivity and firm markups. Using the German-matched employee-employer dataset for $1993-2017$, I analyze this relationship empirically and find that the average German firm charges a price that is 50% higher than the marginal cost, there is positive labour market sorting, and workforce productivity and markups follow an inverted-U relationship. To explain the latter, I develop a theoretical model. The model suggests that firms' incentives to enter the market and asymmetric information on the consumers' side can explain such an empirical relationship.

The second chapter analyzes the relationship between firms' access to export markets and innovations. In the chapter, I argue that corruption levels in firms' countries of origin matter for understanding how export demand shocks impact firms' investments in R&D. I develop a theoretical model which predicts that the export demand shocks should benefit the R&D investments of firms from non-corrupt states more than the innovations of firms from corrupt countries. I test this prediction empirically and find that the export demand shock is positively associated with R&D investments of firms originating from non-corrupt states. I do not find a statistically significant association between the export shocks and R&D investments of firms from corrupt countries.

Finally, using a theoretical model, the third chapter investigates the impact of competition on innovations in vertically related markets. In the model, I consider sectors composed of innovating upstream firms supplying their products to non-innovating downstream ones. The model predicts that the firms' innovation incentives change non-monotonically with the corruption levels in both upstream and downstream markets.

Contents

Introduction

Innovation and productivity play important roles in shaping the competitiveness and growth trajectories of firms and economies. Understanding these factors is essential for policymakers and businesses seeking to foster sustainable development and prosperity. The overall theme of this thesis revolves around exploring the relationship between innovation, productivity, and market dynamics. Through a series of empirical and theoretical analyses, the thesis aims to shed light on questions surrounding the drivers and implications of innovation, firm behaviour, and market structures. The thesis is composed of three chapters, each analyzing different aspects of innovation and productivity.

The first chapter explores the relationship between productivity and market power. More precisely, the chapter aims to understand whether hiring productive workers increases or diminishes firm-level markups. To start with, using the German-matched employee-employer dataset for $1993 - 2017$, I analyze the markup-worker productivity relationship empirically. The empirical results suggest that markups and employees' productivity have an inverted-U-shaped relationship. That is, for firms employing low-productive workers, increasing the average skill level of employees pushes markups up. However, improving employee skill levels can be detrimental to markups for firms employing highly productive workers. To understand the economic factors that may cause such a relationship, I develop a theoretical model. In the theoretical analysis, I show that firms' incentives to enter the markets and asymmetric information on the consumers' side can explain this relationship.

The second chapter analyzes the relationship between exports and innovations. I ask, "Why do innovations of similar firms from different countries respond differently to the same export demand shocks in the same industries?". In the chapter, I argue that the corruption levels in firms' countries of origin can help to answer this question. I develop a theoretical model which shows that firms originating from non-corrupt states should be more productive than the ones from corrupt countries. Therefore, the model predicts that if the overall impact of an export demand shock on firm-level R&D is positive, innovations of firms from non-corrupt states will go up more than the innovations of firms from corrupt states. However, if the overall impact is negative, R&D investments of firms from non-corrupt states will decline less than the investments of firms from corrupt countries. It can also be possible for R&D investments of firms from corrupt countries to decline/stay the same, but the investments of the ones from non-corrupt states to go up, but not vice-versa. To test the model's predictions empirically, I construct a measure of corruption using data from three different non-governmental organisations and employ firm-level data that covers firms from 123 different countries. The empirical results suggest that export demand shocks are positively associated with R&D investments of firms originating from non-corrupt states. However, I do not find a statistically significant association between the export shocks and R&D investments of firms from corrupt countries.

Finally, *the third chapter* investigates the impact of competition on innovations in vertically related markets. I develop a theoretical model in which an economy comprises of upstream firms that innovate and supply their products to non-innovating downstream firms. The aim of this chapter is to analyze how competition in both upstream and downstream markets impacts firms' incentives to innovate. The model predicts that in the innovating (upstream) sectors, the effect of competition varies with market concentration. More precisely, if the innovating sector is oligopolistic, higher levels of competition encourage firms to innovate more. If, instead, the innovating sector is occupied by a monopolist that faces an entrant, firms' incentives to innovate decline with higher levels of (post-entry) competition. Moreover, I show that the innovation incentives of upstream firms either decline with the higher level of competition in the non-innovating (downstream) sectors or have a U-shape relationship with it.

Chapter 1

Labour Productivity and Firm Markups: Insights from the German Labour Market

1.1 Introduction

There has been a growing interest in estimating firm-level markups and explaining their evolution. Interest in this field has been growing after several papers reported increasing firm-level markups in the US over time, and researchers focused on explaining this increase[1]. This paper, instead, attempts to understand how firms' labour market outcomes impact the markups they charge. More precisely, I attempt to answer the question, "Does hiring productive workers increase or diminish firm-level markups?".

To answer this question empirically, I estimate markups using the production approach, as in De Loecker et al. (2020) and De Loecker and Warzynski (2012). I assume that firms employ workers that are heterogeneous in their productivity levels and use capital and *efficiency* units of labour as inputs. The expression for markups is derived from the first-order conditions of a representative firm's cost minimization problem, which suggests that markups can be expressed as the product of elasticity of output with respect to efficiency units of labour and inverse labour share in value-added.

1. De Loecker et al. (2020) and Autor et al. (2020) etc.

Using the information on firms' balance sheet items from the German matched employee-employer dataset for $1993 - 2017$, I estimate the output elasticities following Levinsohn and Petrin (2003) and Ackerberg et al. (2015), and calculate markups. The average estimated markups across all firms over the sample period is 1.5, which is very similar to the ones reported in the literature for Germany and the US. However, contrary to the recent reports for the US economy, I find a slight decline in average German markups over the sample period.

The potential drawback of the production approach in estimating markups is that it assumes that firms are price takers in input markets, and it completely abstracts from modelling the supply side of a given input. Following closely the structural model developed in Lamadon et al. (2022), I illustrate how the expression for markups can be derived in a model in which firms have monopsony power in the labour market, and workers with heterogeneous productivities choose which firms to be employed at. In the model, workers of different productivities maximize utility and choose which firms to work for based on wages and amenities that firms offer. Cost-minimizing firms are assumed to have market power in the output market, face an upward-sloping labour supply curve and choose what amount of each worker type to hire. I show that the expression for markups derived in such a model equals the markup expression from the production approach multiplied by the labour market markdown.

To estimate workers' productivity levels, I assume that individual employee wages can be expressed as a function of time-invariant worker and firm fixed effects, individual-level time-varying controls, and the error term. In the text, I argue that the worker-fixed effects estimated from such a wage equation can be interpreted as workers' underlying productivities. Following Abowd et al. (1999), I apply the AKM model to estimate the worker productivity parameters using the German-matched employee-employer dataset. In addition, I correct for limited mobility bias using the method developed in Bonhomme et al. (2019). The results suggest that 84% of the variation in individual wages of German employees can be explained by worker productivity. In addition, I find that the correlation between worker and firm fixed effects is around 0.13, which suggests positive sorting in the German labour market.

In the text, I show that the expression for markups can also be expressed as a function of worker productivity parameters. However, this expression suggests that the relationship between worker productivity and markups is ambiguous, and empirical results confirm this. Once equipped with the estimates of markups and worker productivity, I estimate the relationship between them using non-parametric regression. The estimates suggest that this relationship is of an inverted U shape. That is, for firms employing low-productive workers, increasing the average skill level of employees pushes markups up. However, improving employee skill levels can be detrimental to markups for firms employing highly productive workers.

Even though the empirical approach used in the text provides a framework to estimate markups and worker productivity parameters, it is silent about the economic factors that derive the observed inverted-U relationship. I developed a theoretical model that helps answer "What may cause markups and worker productivity to have an inverted-U relationship?". As it turns out, firms' incentives to enter the markets and asymmetric information on the consumers' side can explain this relationship.

The theoretical framework is based on step-by-step innovation models, as in Aghion et al. (2001), Aghion et al. (2005), and Akcigit and Ates (2021). The model assumes that each product can be supplied by monopolists or duopolists. Monopolists face entrants that can innovate and enter the market, turning that market into a duopoly. Duopolists can improve efficiency by innovating and becoming a monopolist. As monopolists are sole suppliers of a product, markups in such sectors are higher than in oligopolies. I assume that firms with productive employees produce better quality products and so face high demand. Further, the model assumes that because of asymmetric information, consumers cannot distinguish between product qualities if there are two firms operating in the market.

What derives the inverted-U relationship is the incentives of entrants to enter the market, which depend on two counteracting effects. The negative one is the *cost effect*, which states that it is harder to compete with incumbent monopolists employing productive workers, and so it is costlier to enter into industries where monopolists employ skilled workers. The positive one is the *demand* *effect*, which implies that if an incumbent monopolist employs a productive worker, demand in that market is high due to the positive relationship between worker productivity and product quality. Thus, in case of entry, due to asymmetric information among consumers, an entrant can benefit from this high demand, even if it doesn't produce a high-quality product.

The model predicts that if the cost of entry is concave, there is a cutoff in worker productivity, below which the cost effect dominates the demand effect, pushing down entry into sectors and so increasing markups. However, above that cutoff point, the demand effect starts to dominate, which implies that entrants find it increasingly profitable to enter and benefit from high demand. This, in turn, pushes up entry and so reduces markups, deriving the inverted-U relationship.

This chapter is organized as follows. Section 1.2 derives the expression for markups. Section 1.3 describes the empirical approach used to recover the worker productivity parameters, followed by the description of data sources in Section 1.4. Section 1.5 discusses the estimation procedures and presents empirical results. Finally, Section 1.6 develops the theoretical model.

1.2 Deriving the expression for markups

Consider a firm j with production function given by:

$$Y_{jt} = F(A_{jt}, K_{jt}, L_{jt})$$

where $F(\cdot)$ is assumed to be a continuous and twice differentiable function with respect to its arguments. A_{jt} is the firm specific productivity parameter, K_{jt} is the amount of capital stock that the firm j has at time t, and L_{jt} is the total efficiency units of labour. Let $E_{jt}(X)$ be the amount of labour with productivity X employed by firm j. Then, the efficiency units of labour, L_{jt}, is defined as:

$$L_{jt} = \int X E_{jt}(X) dX$$

I assume that each firm takes wages of each labour type, $W_t(X)$, and the rental rate of capital, r_t, as given and minimizes its costs. The corresponding Lagrangian function of the cost minimization problem is given by:

$$\min_{E_{jt}(X),K_{jt}} \left\{ \int W_t(X)E_{jt}(X)dX + r_t K_{jt} + \lambda_{jt}\Big(Y_{jt} - F(A_{jt}, K_{jt}, L_{jt})\Big) \right\}$$

Lemma ME1 in Appendix ME1 shows that the first-order conditions of this minimization problem yield to the following expression for firm-level markups:

$$\mu_{jt} = \theta^L_{jt}\left(\frac{P_{jt}Y_{jt}}{B_{jt}}\right) \tag{1.1}$$

where $\theta^L_{jt} \equiv \left(\frac{\partial F(\cdot)}{\partial L}\frac{L}{Y}\right)$ is the elasticity of output with respect to efficiency units of labour, $P_{jt}Y_{jt}$ is value-added and $B_{jt} = \int W_t(X)E_{jt}(X)dX$ is the total wage bill. Note that the expression for markups is almost identical to the one in De Loecker et al. (2020), with the only difference being the elasticity of output, in this case, is with respect to efficiency units of labour, but in the case of De Loecker et al. (2020) it is with respect to physical units of labour.

To better understand the role of worker productivity in determining markups, the corollary to Lemma ME1 shows that the same expression for markups can also be expressed as follows:

$$\mu_{jt} = \theta^L_{jt}\frac{P_{jt}Y_{jt}}{L_{jt}}\frac{\left(\int XdX\right)_{jt}}{\left(\int W_t(X)dX\right)} \tag{1.2}$$

Thus, the markup of a firm j at time t can be shown to be a function of the elasticity of output with respect to efficiency units of labour, the inverse of total wages paid to each labour type X, the total skill level of workers at a firm, and value-added per efficiency units of labour. Expressing markups, as in (1.2), implies that the relationship between firm markups and workforce skill sets is ambiguous. Hiring high-productivity workers increases the marginal productivity of a *unit of labour*, which influences markups positively through ($\int XdX$) term. However, if there is a diminishing marginal productivity of *efficiency units of labour*, hiring highly productive workers may harm markups through $\frac{P_{jt}Y_{jt}}{L_{jt}}$ term. High-productivity workers would be expected to demand higher wages, which in turn diminishes markups further, which is expressed by ($\int W_{jt}(X)dX$) term. Overall, the expression for markups does not have a clear prediction regarding how worker productivity should be correlated with markups.

The derivation of markups above assumes that firms take factor prices as given. Moreover, it abstracts from the workers of different productivities choosing which firms to work for. Appendix ME2 illustrates how the expression for markups can be derived in a model that accounts for workers' choice of which firms to be employed at and for firms' monopsony power. The expression for markups largely remains the same as in (1.1).

In practice, I estimate markups as in expression (1.1). However, to estimate that, one needs to recover the elasticity of output with respect to the efficiency units of labour, which depends on worker productivity parameters. Next, I describe the empirical strategy implemented to recover the worker productivity parameters, X.

1.3 Recovering the worker productivities

Let $\omega_{i(j)t}(x)$ be the log-wage rate that a worker i with (log) productivity x_i earns at firm j at time t. I assume that the log of wage of a worker i employed at firm j is given by:

$$\omega_{i(j)t}(x) = x_i + \psi_j + P'_{it}\beta + \varepsilon_{it} \tag{1.3}$$

where ψ_j is the firm fixed effect, P_{it} is a vector of time-varying controls (e.g. education, experience, year fixed effects), and ε_{it} captures the unobserved time-varying error. The term x_i is the (log) worker productivity parameter ($\log(X_i)$).

To see why x_i can be treated as the worker productivity parameter, note that it is the person-specific fixed effect that captures the time-invariant portable component of earnings ability. That is, following Card et al. (2013), the parameter x_i can be interpreted as "a combination of skills and other factors that are rewarded equally across employers". In this text, I refer to such a combination of skills as "productivity".

I estimate the worker productivity parameters, alongside firm fixed-effects and β, following the AKM model developed by Abowd et al. (1999). In section 1.5, I describe in detail this estimation procedure and the methods implemented to correct the incidental parameters problem, known as the mobility bias.

1.4 Data

To estimate the markups and worker productivities, I use the linked employee-employer panel dataset (LIAB) from the German Institute for Employment Research (IAB) from 1993 to 2017. This dataset links the information on firms obtained from the annual IAB Establishment Panel with the data on individual employees from the Integrated Employment Biographies (IEB).

1.4.1 IAB Establishment Panel

The sample of firms chosen to be interviewed for the establishment panel is drawn from the population of all German establishments with at least one employee liable to social security contributions as of the reference date of the 30^{th} of June of the previous year. Each firm in the panel is assigned a unique establishment number, which is used to construct a panel and link it to the employee data. The questionnaires that firms fill out cover many areas, with some of the questions being discontinued or changed. Fortunately, for this paper, the questions on value-added, sales, the total wage bill, the number of employees and expenditure on intermediate materials have been continuously asked since 1993.

In a given year, the questions on value-added, the total wage bill and material expenditures ask about the amounts in the previous fiscal year. The reported number of employees in a given year is as of the 30th of June of that year. Other than these variables, I also use information on industry classification and the German state in which a company is located. Using the industry classifications, I aggregate the industries into seven *broad* industry groups (e.g., Manufacturing, Services, etc.), and I define a *market* as a combination of aggregated industry and a State (e.g., Manufacturing-Brandenburg, Agriculture-Saxony, etc.). The establishment panel doesn't provide any information on the capital stock of firms. I estimate each firm's capital stock using the perpetual inventory method, following Muller (2010).

1.4.2 Integrated Employment Biographies

The information on individual workers originates from two sources: Employee History (Beschäftigtenhistorik – BeH) and Benefit Recipient History (LeH). The Employee History includes information on employment subject to social security and marginal part-time employment, whereas the Benefit Recipient History provides information on benefit recipients, such as unemployed individuals. Because of the size restrictions, only for a selected subsample of the IAB Establishment Panel firms, it is possible to observe all workers of an establishment. Hence, together with the establishment data, the Integrated Employment Biographies allow the construction of the employment biographies of individuals for a subsample of establishments.

To estimate the worker productivity parameters using the AKM model, I need to observe workers in multiple firms, their earnings at those firms, and certain time-varying worker characteristics. Hence, the variables from the individual-level dataset that are important for the purpose of this paper are the following: individual and firm unique ID numbers, the daily wage, workers' age and educational attainments. Worker and firm ID numbers are used to construct employment biographies. Age and educational attainment variables are used in the vector of time-varying controls, P_{jt}.

1.4.3 Sample selection

I restrict the sample to individuals working full-time at one firm at a given time, earning more than 10 EUR per day. If an individual is employed at more than one firm at a given time, I choose their primary employer as the firm that pays the highest wage to that worker. After dropping the firms with missing information on at least one of the above-mentioned variables, the total number of observations in the merged employee and firm dataset is $3,196,320$, with $618,829$ unique workers in $14,331$ unique firms over $1993 - 2017$.

To estimate the worker productivity parameters, I consider the subsample that includes the workers observed at multiple firms (i.e., *movers* sample). I restrict this sample to workers with at least ten data points. Further, I only consider the largest connected set in the sample.

1.5 Estimation procedure and empirical results

In this section, I describe how I estimate the worker productivity parameters and markups in practice and provide the empirical results. Additionally, I analyze the relationship between markups and worker productivity.

1.5.1 Estimation of worker productivities and correcting the mobility bias

To estimate the wage equation in (1.3), I use a two-way fixed effects approach, introduced by Abowd et al. (1999) (AKM model). I restrict the data to the largest connected set of firms and workers. Following Card et al. (2013), as time-varying controls, P_{jt}, I include year dummies, quadratic and cubic terms in age fully interacted with educational attainment.

Due to the large number of firm effects that need to be identified from workers who move across firms, the AKM model suffers from incidental parameters problem, often referred to as "limited mobility bias". This problem has been highlighted in Abowd et al. (2004), and Andrews et al. (2008) reported that the bias can be substantial. More recently, Bonhomme et al. (2023) and Lamadon et al. (2022) showed that the bias arising from this incidental parameters problem is a major issue. There have been several proposals regarding how to correct this bias, such as the bias correction methods reported in Andrews et al. (2008), Kline et al. (2020), and Bonhomme et al. (2019). This paper follows the last one to account for this problem.

Following Bonhomme et al. (2019), to correct for the limited mobility bias, I classify the firms into groups according to their empirical wage distributions using the k-means clustering algorithm. More precisely, first, I estimate ten firm classes using the k-means clustering on the overall empirical distribution of wages evaluated on a grid of 10 percentiles[2]. Second, I restrict ϕ_j to be the same across firms in the same group and apply a two-way fixed effects model to estimate the worker and firm parameters.

The results *without* correcting for limited mobility bias suggest that around 75.2% of the wage variation can be explained by worker productivity. Moreover, the correlation between worker and firm effects is found to be 0.0046. However, after correcting for mobility bias, this correlation rises to 0.13, which suggests small, albeit positive, sorting in the German labour market. For comparison, using the data on West German firms and male employees, Card et al. (2013) reports that the correlation between person and establishment fixed effects is in the interval of $0.03 - 0.25$, depending on the time period used to estimate the fixed effects.

The share of variation in individual wages that can be explained by worker productivity goes up to 84% after correcting for mobility bias. This change aligns with what Lamadon et al. (2022) finds. They report that, after correcting for mobility bias, the role of worker effects in explaining the variation in wages increases and the correlation between work and firm effects also goes up.

1.5.2 Estimation of output elasticities

Equipped with the estimates of worker productivity parameters, I need to estimate the elasticity of output with respect to efficiency units of labour in order to calculate markups. Given that the productivity parameter cannot be identified for every single employee at a given establishment (e.g. employees that never change their jobs), I construct efficiency units of labour as the average estimated employee productivity, $\overline{X}$, in a given establishment at time t, multiplied by the number of workers employed at that establishment in the same year.

2. Results are robust to the choice of the number of clusters or percentiles.

I consider a (broad) industry-specific Cobb-Douglas production function with efficiency units of labour and capital as inputs. That is, for every industry s, I assume that the production function is of the following form:

$$y_{jt} = \theta_s^L l_{jt} + \theta_s^K k_{jt} + \rho_{jt} + \epsilon_{jt}$$

where the lowercase letters denote logs (i.e. $y_{jt} = \log(Y_{jt})$). Following the literature, ρ_{jt} denotes the productivity shock, and ϵ_{jt} is the measurement error in the output. Note that by following this approach, I restrict the output elasticities of firms operating in a given industry s to be the same and time-invariant:

$$\theta_{jt}^L = \theta_{j't}^L = \theta_s^L \quad \text{if} \quad s(j) = s(j') = s$$

I estimate the above production function following Levinsohn and Petrin (2003), by implementing the correction introduced in Ackerberg et al. (2015). Capital at time t is treated as the state variable, l_{jt} is the dynamic input, and (log) expenditure on materials is the proxy variable. The results suggest that the average of θ_s^L across the industries is estimated to be 0.6.

1.5.3 Estimation of markups

Using the estimates of the elasticity of output with respect to efficiency units of labour, I estimate markups following the expression in (1.1). The average markup across all firms over $1993 - 2017$ is estimated to be 1.5. This implies that an average German firm has significant market power. The average of firm-level markups found in this paper is similar to the ones reported in the literature. For instance, markups for the US firms are reported in the range of $1.2 - 1.8$[3], in Slovenia, they are found to be around $1.17 - 1.28$[4]. Using the Worldscope dataset, De Loecker and Eeckhout (2021) reports that the average of global markups is in the range of $1.1 - 1.6$. In other papers, markup estimates for Germany are found to be around $1.4 - 1.5$[5].

Figure 1.1 in Appendix MF shows that there is a slight declining trend in the evolution of

3. De Loecker et al. (2020) and Autor et al. (2020).
4. De Loecker and Warzynski (2012)
5. Weche and Wagner (2020) and Ganglmair et al. (2020).

(unweighted) average markups in Germany from $1995-2017$. This result is in stark contrast with recently reported increasing markups for the US. For Germany, Weche and Wagner (2020) analyses markups for $2005-2013$ and does not find an upward or downward trend in the evolution of average markups.

1.5.4 Markups and worker productivities

After estimating the markups and worker types, I can analyze the relationship between these two variables. To this end, I group firms into clusters based on average and median worker-type distribution. More precisely, I divide the distribution of firm-level average and median worker types into a grid of 10 percentiles. Then, I estimate how markups change depending on which cluster they belong to. To flexibly capture the heterogeneity of markups by worker types, I run non-parametric regression of the following type:

$$\ln\left(\mu_{jt}\right) = \beta_0 + \sum_{c=1}^{C} \beta_c \times D_{g_{jt} \in C_c} + \mathbf{X}'_{jt}\beta_X + \nu_{jt} \tag{1.4}$$

where $D_{g_{jt} \in C_c}$ is a dummy variable indicating whether a firm j belongs to cluster C_c at time t, where the number of clusters is set to 10. $\mathbf{X}_{jt}$ includes a set of industry, region, and year fixed-effects. I estimate the above regression for clusters formed based on firm-level average and median worker types separately.

Figures 1.2 and 1.3 in Appendix MF report the results. The bootstrapped standard errors indicate that all estimates are statistically significant. As can be seen from the figures, regardless of whether the average or median worker types are used for the regressions, the relationship between firm markups and worker productivity appears to be inverse U-shaped. At low levels of worker productivity, increasing average or median worker productivity increases markups. However, firms at the higher end of worker types' distribution experience a decline in their markups. Tests using bootstrapped standard errors to analyze whether the observed estimates differ from each other confirm the inverted-U relationship.

Even though it was discussed in Section 1.2 that the relationship between markups and worker productivity is expected to be ambiguous, the empirical approach used so far is silent regarding the economic forces that derive this result. The remainder of the paper develops a theoretical model to uncover the factors that can explain this inverse-U shape.

1.6 Theoretical model

This section develops a theoretical model to explain the economic forces that derive the observed inverse-U-shaped relationship between firm markups and workforce skill sets. The framework is based on step-by-step innovation models of endogenous growth, as in Aghion et al. (2001), Aghion et al. (2005), and Akcigit and Ates (2021). Similarly to those models, each product is supplied by at most two oligopolists. Oligopolists can improve efficiency by innovating and becoming monopolists. Current monopolists face entrants who can innovate and enter the market. However, there are three crucial differences between the established models of step-by-step innovation and the one in this chapter. First, demand for a product is influenced by the quality of that product, which in turn is determined by the skill set of a firm's employees supplying that good. Second, as a result of asymmetric information, consumers cannot distinguish between product qualities if there are two firms operating in the market. Finally, firms do not directly choose innovation intensities. Instead, firms choose what productivity labour to hire, which in turn affects their chances of successful innovation.

1.6.1 Consumers

I assume that time is discreet and there is a $L > 1$ mass of identical consumers who make decisions only for one period ahead. Each consumer's utility depends on a continuum of goods of measure F and the function is given by:

$$U_{it} = \int_0^F q_{jt} \ln\big(y_{jt}\big) dj \tag{1.5}$$

where q_{jt} is the quality level of good in sector j at time t, and y_{jt} is the amount of the product produced in sector j at time t. In monopolistic sectors, y_{jt} is supplied by one firm, and in duopolies, the amount of the good produced in sector j is the sum of the amounts produced by each firm in that sector:

$$y_{jt} = y_{1jt} + y_{2jt}$$

The representative consumer maximizes her utility function, subject to her budget constraint given by $\int_0^F p_{jt}y_{jt} = E$, where expenditure, E, is normalized to 1. As it is shown in Lemma MT1 in Appendix MT1, demand for product j is given by:

$$y_{jt} = L\frac{q_{jt}}{Q_t}\frac{1}{p_{jt}}$$

where $Q_t = \int_0^F q_{jt}$ is the aggregate quality at time t,. Thus, demand for product j depends not only on its price but also on how high or low the quality of that product is relative to the total quality.

1.6.2 Firm production and profits

A firm with efficiency level A_{jt} hires l_{jt} number of manufacturing labour and one manager to produce output y_{jt}. Manufacturing labour is assumed to be of the same productivity, supplying labour inelastically at some wage w^u. Managers, denoted by M, can be of a productivity $x > 1$, and firms choose what productivity manager to hire in a spot market[6]. Managers' wages are determined as a result of Nash Bargaining.

A firm's production function is given by:

$$y_{jt} = A_{jt}l_{jt}M(x)$$

6. This model abstracts from workers of different productivities choosing what firms to work for. Thus, if a firm decides to hire a manager of productivity x, that manager is readily available for employment. Formally, this assumes that there is a large enough mass of managers of a given productivity, and the managers' outside options are zero. I recognize that modeling the workers' choices of which firms to work for will be an important extension of this model and will provide a more complete analysis.

Given that each firm hires one manager, the production function becomes:

$$y_{jt}(x) = A_{jt} l_{jt}$$

The production function implies that the marginal cost function is:

$$MC_{jt} = \frac{w^u}{A_{jt}}$$

If one of the firms has a higher efficiency level, A_{jt}, than the other, that firm is a monopolist. Entrants can enter the market if they successfully innovate and reach the same level of efficiency as the incumbent firm. Thus, in duopolies, both firms are on the same efficiency level.

In order to determine the price charged in each sector, consider a monopolist with efficiency level A_{jt}, facing an entrant with efficiency level A_{-jt}, with $A_{jt} > A_{-jt}$. Such a monopolist will always charge a price that is (weakly) lower than the entrant's marginal cost: $p_{jt}^M \leq \frac{w^u}{A_{-jt}}$. The reason for that is that at any higher price, the entrant will find it profitable to enter the market, which will reduce the profits that the monopolist can capture. Thus, the maximal feasible price that a monopolist can charge is $p_{jt}^M = \frac{w^u}{A_{-jt}}$. Therefore, the gross profit that a monopolist makes is given by:

$$\pi_{jt}^{MG}(x) = y_{jt} p_{jt} - \frac{w^u}{A_{jt}} y_{jt} \quad \text{subject to} \quad y_{jt} = L \frac{q_{jt}}{Q_t} \frac{1}{p_{jt}}, \quad p_{jt} = \frac{w^u}{A_{-jt}}$$

Combining the constraints and substituting them into the profit function implies:

$$\pi_{jt}^{MG}(x) = L \frac{q_{jt}}{Q_t} \left(1 - \frac{A_{-jt}}{A_{jt}}\right)$$

For simplicity, I assume that the knowledge spillovers between a monopolist and an entrant are high enough so that the efficiency gap between them is no larger than $G > 1$. This assumption implies that $\frac{A_{-jt}}{A_{jt}} = 1/G$, and so $\pi_{jt}^{MG}(x) = L \frac{q_{jt}}{Q_t} \left(1 - \frac{1}{G}\right)$.

If an entrant successfully manages to reach the incumbent's efficiency level A_{jt}, then it will enter the market, and the sector will become a duopoly. I assume that duopolists collude and each charges the same price above its marginal cost:

$$p_{jt}^{D} = \frac{w^{u}}{A_{jt}}\Delta, \quad \text{for} \quad G > \Delta > 1$$

As a result, the duopolists will share the market, and each supply half of the demand. Thus, each duopolist will make the profits given by:

$$\pi_{jt}^{DG} = L\frac{q_{jt}}{2Q_t}\left(1 - \frac{1}{\Delta}\right)$$

The managers and the firms bargain á la Nash (1950) over the firms' profits in order to determine the managers' compensation. If a manager's bargaining power is given by $\beta \in (0, 1)$, then, as shown in Lemma MT2, the firms' net profits are:

$$\pi_{jt}^{M}(x) = L\frac{q_{jt}}{Q_t}\left(1 - \frac{1}{G}\right)\left(1 - \beta\right) \quad \text{and} \quad \pi_{jt}^{D} = L\frac{q_{jt}}{2Q_t}\left(1 - \frac{1}{\Delta}\right)\left(1 - \beta\right)$$

1.6.3 Product quality

So far, no structure has been imposed on q_{jt}. The crucial assumption of this model is the quality of a product produced by a firm depends on how skilled the workforce of the firm supplying that product is. More precisely, I assume that the more skilled a firm's labour is, the better quality products that firm can produce. As the manufacturing labour is assumed to be of homogeneous productivity, the heterogeneity in product quality among firms will depend on the skill levels of managers that the firms hire[7].

If a product is supplied by a monopolist and its manager's productivity is x_{jt}^{M}, the quality of that product j is determined by the $g(x_{jt}^{M})$ function:

$$q_{jt}^{M} = g(x_{jt}^{M})$$

7. In this text, I use the expressions "skilled manager", "skilled workforce" and "skilled labour" interchangeably.

such that

$$\frac{dg(x_{jt}^M)}{dx_{jt}^M} > 0 \quad \text{and} \quad \frac{d^2 g(x_{jt}^M)}{d\big(x_{jt}^M\big)^2} \leq 0$$

The first derivative captures the assumption that highly skilled workers produce better-quality products. The second assumption implies that this relationship is concave[8].

Even though consumers can identify the quality level of a product produced by a monopolist, it is assumed that due to asymmetric information, consumers are unable to distinguish between the qualities of products supplied by duopolists. Thus, in duopolies, the perceived quality of a product j is given by the average of qualities of each firm supplying j:

$$q_{jt}^D = \frac{g(x_{1jt}^D) + g(x_{2jt}^D)}{2}$$

Using the assumptions on q_{jt}, the profit functions can be expressed as:

$$\pi_{jt}^M(x) = \frac{L}{Q_t} g(x_{jt}^M)\Big(1 - \frac{1}{G}\Big)\Big(1 - \beta\Big)$$

$$\pi_{jt}^D = \frac{L}{2Q_t}\frac{g(x_{1jt}^D) + g(x_{2jt}^D)}{2}\Big(1 - \frac{1}{\Delta}\Big)\Big(1 - \beta\Big)$$

As can be seen, the asymmetric information assumption regarding product quality yields to an interesting feature of the model. In duopolies, the profit that each firm makes increases in *both* firms' workforce productivity levels. Therefore, in oligopolistic markets, the firm with a low productive manager can enjoy high demand if the rival employs high-skilled labour.

1.6.4 Innovation, entry, and exit

For simplicity, I assume that firms only make decisions one period ahead. Thus, at time $t = 0$, firms make decisions only for time $t = 1$. Moreover, it is assumed that a firm's probability of a successful innovation depends on how skilled its manager is. More precisely, I assume that firms with highly

8. The concavity assumption is made for mathematical convenience.

skilled managers have a higher chance of successful innovation.

Consider a sector occupied by an incumbent monopolist. Monopolists will not innovate in this setup, as the efficiency gap between a monopolist and an entrant can never exceed G because of knowledge spillovers. Hence, only entrants innovate in such sectors, and as a result of successful innovation, they reach the incumbent firms' efficiency levels and enter the market. Let $p(x_{-1})$ be the probability of successful innovation by an entrant, which depends on the skill level of a manager that the entrant chooses to hire, x_{-1}. I assume that the function $p(\cdot)$ satisfies the following conditions:

$$\frac{dp(x)}{dx} > 0 \quad \text{and} \quad \frac{d^2p(x)}{dx^2} \leq 0$$

The first condition assumes that the more productive a firm's manager is, the better the chances of successful innovation. The second assumption assumes that this relationship is concave.

If the incumbent monopolist employs a manager with skill x_1, an entrant's objective function is given by:

$$\Pi_{-1} = p(x_{-1})\frac{L}{Q_t}\left(\frac{g(x_{-1}) + g(x_1)}{2}\right)\pi_0 - \frac{x_{-1}^2 x_1^\gamma}{2}$$

where $\pi_0 = \frac{1}{2}\Big(1 - \frac{1}{\Delta}\Big)\Big(1 - \beta\Big)$ and $0 < \gamma < 1$. That is, with probability $p(x_{-1})$ an entrant successfully enters the market, turning it into a duopoly. As it was established earlier, in duopolies, firms collude and each faces demand that is a function of average product quality. With probability $(1 - p(x_{-1}))$, the entrant stays out of the market, earning 0. There is, however, the cost of entering the market, given by $\frac{x_{-1}^2 x_1^\gamma}{2}$. The cost is increasing in the entrant's own manager skill level, reflecting the assumption that it is costlier to find highly skilled workers. The cost is also increasing in the incumbent manager's skill level, which implies that the more skilled the incumbent's manager is, the more difficult it is to compete with that incumbent and enter the market. Entrant chooses x_{-1} to maximize its objective function.

Now, consider oligopolists with manager productivities given by $\overline{x}_0$ and $\underline{x}_0$. In every period, a duopolist chooses what productivity manager to hire in order to innovate and become a monopolist. I will assume that only one of the duopolists has the opportunity to find a new worker and innovate in each period. If a duopolist hires a manager with productivity x_0, then the probability of successful innovation is given by $p(x_0)$. With probability $(1 - p(x_0))$, the industry stays as a duopoly, with both firms retaining their initial managers. Thus, the innovating duopolist's objective function is:

$$\Pi_0 = p(x_0)\frac{L}{Q_t}g(x_0)\pi_1 + (1 - p(x_0))\frac{L}{Q_t}\left(\frac{g(\overline{x}_0) + g(\underline{x}_0)}{2}\right)\pi_0 - \frac{x_0^2}{2}$$

where $\pi_0 = \left(1 - \frac{1}{G}\right)\left(1 - \beta\right)$. Note that, as both firms are already in the market, there is no entry cost.

1.6.5 Equilibrium manager productivity

I assume that each firm is small with respect to the size of the whole economy, and so firms do not take into consideration how their choice of x impacts the aggregate quality level Q_t. Then, maximizing the entrant's objective function implies that the choice of x_{-1} has to satisfy the following first-order condition:

$$\frac{dp(x_{-1})}{dx_{-1}}\frac{L}{Q_t}\left(\frac{g(x_{-1}) + g(x_1)}{2}\right)\pi_0 + p(x_{-1})\frac{L}{Q_t}\frac{1}{2}\frac{dg(x_{-1})}{dx_{-1}}\pi_0 - x_{-1}x_1^{\gamma} = 0$$

Similarly, maximizing the incumbent's objective function yields to:

$$\frac{dp(x_0)}{dx_0}\frac{L}{Q_t}g(x_0)\pi_1 + p(x_0)\frac{L}{Q_t}\frac{dg(x_0)}{dx_0}\pi_1 - \frac{dp(x_0)}{dx_0}\frac{L}{Q_t}\left(\frac{g(\overline{x}_0) + g(\underline{x}_0)}{2}\right)\pi_0 - x_0 = 0$$

Given the equilibrium expressions for x_{-1} and x_0, the following lemma formally proves how the choices of manager productivities by firms change with the rivals' managers' skills:

Lemma MT3:

Suppose that the mass of workers is such that $L < \frac{Q}{2\pi_1 \frac{dp(x)}{dx}\frac{dg(x)}{dx}}$ for any x. Then, x_0 declines in both own and rival's manager productivity, and the relationship between x_{-1} and x_1 is U-shaped:

$$\frac{dx_0}{d\underline{x}_0} < 0 \quad \text{and} \quad \frac{dx_0}{d\overline{x}_0} < 0$$

$$\frac{dx_{-1}}{dx_1} < 0 \quad \text{if} \quad x_1 < \left(\frac{\gamma x_{-1}}{\frac{L}{2Q}\frac{dp(x_1)}{dx_1}\frac{dg(x_1)}{dx_1}\pi_0} \right)^{\frac{1}{1-\gamma}}, \quad \text{and} \quad \frac{dx_{-1}}{dx_1} > 0 \quad \text{if} \quad x_1 > \left(\frac{\gamma x_{-1}}{\frac{L}{2Q}\frac{dp(x_1)}{dx_1}\frac{dg(x_1)}{dx_1}\pi_0} \right)^{\frac{1}{1-\gamma}}$$

Proof: Appendix MT1

As it will become apparent below, this result is vital to explain the inverted-U-shaped relationship between markups and worker productivity, and the intuition behind it is very simple. A duopolist's incentive to innovate and become a monopolist depends on the difference between the current profits that it is making and the profits that it will make as a monopolist. The higher the difference between these profits is, the higher the incentives of a duopolist to become a monopolist. Due to asymmetric information among consumers, the rival's manager's productivity positively impacts market demand. Hence, the larger the rival's manager's productivity is, the higher the current profits that a duopolist is making. I refer to this effect as the *demand effect.* It implies that the difference between the monopolist and current profits declines, which reduces the incentives to innovate, and so x_0 declines.

Similarly, an entrant compares its current profits to the ones after entry when deciding what productivity manager to hire in order to enter. However, an entrant's pre-entry profits are zero. Thus, due to the demand effect, the higher the incumbent monopolist's manager's skill level is, the larger the post-entry profits, which increases the incentives for an entrant to hire a skilled manager to increase the chances of entry. However, this also implies that the cost of entry is higher, as it is more difficult to compete with an incumbent employing a productive manager. I refer to the latter as the *cost effect* and it reduces the incentives to enter. The model predicts that, due to concave entry costs, the latter negative effect dominates the positive one for small values of x_1. However, as x_1 increases, the demand effect starts to dominate, increasing the incentives to enter, and the entrant hires a more productive manager.

Also note that, as $\frac{dp(\cdot)}{dx} > 0$, the probabilities of successful innovation change in the same way as x in Lemma MT3. In the next section, I will describe how these results shape the aggregate markups.

1.6.6 Markups

Markups are defined as the difference between the price that a firm charges and its marginal cost, divided by marginal cost:

$$\mu_{jt} = \frac{p_{jt} - MC_{jt}}{MC_{jt}}$$

Recall that a monopolist with efficiency level A_{jt} has marginal cost given by $MC_{jt} = \frac{\omega^u}{A_{jt}}$ and charges $p_{jt} = \frac{\omega^u}{A_{-jt}}$, where A_{-jt} is the efficiency level of an entrant that a monopolist is facing. Thus, markup in a sector that is occupied by an incumbent monopolist is given by:

$$\mu^M = \frac{p_{jt}}{MC_{jt}} - 1 = \frac{A_{jt}}{A_{-jt}} - 1 = G - 1$$

where I used the assumption that the efficiency gap between a monopolist and an entrant cannot be greater than $G > 1$.

Similarly, as was discussed above, each duopolist charges $p^D_{jt} = MC_{jt}\Delta$, for $G > \Delta > 1$. Thus, markups in duopolies are given by:

$$\mu^D = \Delta - 1$$

Note that, as $G > \Delta > 1$, it must be the case that $\mu^M > \mu^D$.

In order to obtain aggregate markups, one needs to know the distribution of monopolies and oligopolies at time $t = 1$. To obtain the distributions, I assume that in the initial time period, $t = 0$ the measure of monopolies with manager skill level $\tilde{x}$ is given by $\psi^M_0(\tilde{x})$ and the measure of oligopolies is given by $\psi^D_0(\tilde{x})$, such that $\frac{\overline{x}_0 + \underline{x}_0}{2} = \tilde{x}$. Further, assume that, for simplicity, the measure of all monopolies and all oligopolies at time $t = 0$ is the same. That is:

$$\psi^M_0(\tilde{x}) = \psi^M \quad \forall\tilde{x}; \quad \psi^D_0(\tilde{x}) = \psi^D \quad \forall\tilde{x}$$

Then, the measure of monopolies that employ managers with skill level $\tilde{x}$ at time $t = 1$ is given by:

$$\psi_1^M(\tilde{x}) = \psi^M\Big(1 - p(x_{-1}|\tilde{x}) + p(\tilde{x}_0|\hat{x}_0)\Big)$$

where $p(x_{-1}|\tilde{x})$ is the probability that an entrant enters the market with an incumbent monopolist employing a manager with skill $\tilde{x}$. That is, $p(x_{-1}|\tilde{x})$ is the probability of an exit from a monopoly with average skill level $\tilde{x}$. $p(\tilde{x}_0|\hat{x}_0)$ is the probability that an oligopolist from a duopoly with average skill level $\hat{x}_0$ successfully innovates by hiring a $\tilde{x}_0$ manager. Hence, $p(\tilde{x}_0|\hat{x}_0)$ is the probability of an entry into a monopolistic sector with average skill level $\tilde{x}_0$. Similarly, the measure of oligopolies with average skill level $\tilde{x}$ at time $t = 1$ is given by:

$$\psi_1^D(\tilde{x}) = \psi^D\Big(1 - p(x_0|\tilde{x}) + p\big(x_{-1}|2\tilde{x} - x_{-1}\big)\Big)$$

$p(x_0|\tilde{x})$ is the probability of exit from a duopoly with average skill level $\tilde{x}$. $p\big(x_{-1}|2\tilde{x} - x_{-1}\big)$ is the probability of an entrant entering into a monopolistic sector, where the incumbent employs a manager with productivity $\hat{x}_1$, such that post-entry, the average skill level in that industry, given by $\frac{\hat{x}_1 + x_{-1}}{2}$, becomes $\tilde{x}$ [9]. Therefore, $p\big(x_{-1}|2\tilde{x} - x_{-1}\big)$ is the probability of an entry into the duopoly with average skill level $\tilde{x}$.

The following lemma summarizes how the measure of monopolies and oligopolies change with the average skill level in an industry:

Lemma MT4:

The relationship between $\psi_1^D(\tilde{x})$ and $\tilde{x}$ is either U-shaped or it is increasing and convex. The measure of monopolies, $\psi_1^M(\tilde{x})$, has either an inverted-U or increasing and concave relationship with $\tilde{x}$.

Proof: Appendix MT1

Given the previous discussion, this result is not surprising. The higher is $\tilde{x}$, the lower the

9. Thus, the incumbent monopolist's manager productivity in such a sector is expressed as $\hat{x}_1 = 2\tilde{x} - x_{-1}$.

oligopolists' incentives to innovate, which reduces the exit from duopoly sectors and so increases the measure of duopolies. In addition, recall that an entrant's incentives to enter have a U-shaped relationship with the incumbent's manager's skill level. Thus, due to the demand effect, at higher levels of $\tilde{x}$, $p\big(x_{-1}|2\tilde{x}-x_{-1}\big)$ is increasing, which reinforces the increase in $\psi_1^D(\tilde{x})$. However, at lower levels of $\tilde{x}$, $p\big(x_{-1}|2\tilde{x}-x_{-1}\big)$ decreases due to the cost effect, pushing entry into duopolies down. If the cost effect is higher than the positive effect of $p(x_0|\tilde{x})$, we end up with a U-shaped relationship between $\psi_1^D(\tilde{x})$ and $\tilde{x}$. However, if the negative effect of $p\big(x_{-1}|2\tilde{x}-x_{-1}\big)$ is small, then the measure of oligopolies increase at low levels of $\tilde{x}$ as well, albeit at a lower rate.

A similar explanation holds for the measure of monopolies. First, note that the higher $\tilde{x}$ is, the higher the chances of an oligopolist, which employs a manager with $\tilde{x}$, to become a monopolist. This stems from the assumption that the probability of a successful innovation increases with managers' skill levels. Thus, $p(\tilde{x}_0|\hat{x}_0)$ increases with $\tilde{x}$, which pushes up entry into monopolistic sectors. Regarding the exit, as it was established, $p(x_{-1}|\tilde{x})$ has a U-shaped relationship with $\tilde{x}$. Thus, due to the cost effect, at low levels of $\tilde{x}$, entry decreases with higher $\tilde{x}$. This reinforces the increase in $\psi_1^M(\tilde{x})$, caused by $p(\tilde{x}_0|\hat{x}_0)$. However, at high levels of $\tilde{x}$, the demand effect starts to dominate, and entry becomes more attractive, which reduces the measure of monopolies. If this negative effect is higher than the positive effect of $p(\tilde{x}_0|\hat{x}_0)$, then we end up with an inverted-U relationship between the measure of markups and average skill level. However, if the negative effect is smaller than the positive effect of $p(\tilde{x}_0|\hat{x}_0)$, $\psi_1^M(\tilde{x})$ keeps increasing, but at a lower rate.

Given the above distributions of sectors at time $t = 1$, the average markups in a sector with average skill level $\tilde{x}$ is given by:

$$\overline{\mu}_1(\tilde{x}) = \frac{\psi_1^M(\tilde{x})}{\psi_1^M(\tilde{x})+\psi_1^D(\tilde{x})} \times \mu^M + \frac{\psi_1^D(\tilde{x})}{\psi_1^M(\tilde{x})+\psi_1^D(\tilde{x})} \times \mu^D = \frac{\psi_1^M(\tilde{x})}{\psi_1^M(\tilde{x})+\psi_1^D(\tilde{x})} \times \Big(\mu^M - \mu^D\Big) + \mu^D$$

As can be seen from the expression above, as $\mu^M > \mu^D$, markups in an industry with average skill level $\tilde{x}$ increase (decrease) with a higher (lower) fraction of monopolies in that sector. Hence, for an inverted U-shaped relationship between markups and labour skill levels, it must be that the fraction of monopolies has an inverted U-shape relationship with $\tilde{x}$ as well. The next lemma states the conditions when this will hold.

Lemma MT5:

Suppose that the cost and demand effects for entrants are high, such that:

$$\left|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\right| > \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}_0} \quad \text{and} \quad \left|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\right| > \left|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\right|$$

Then, the markups have an inverted U relationship with the average skill levels of managers.

Proof: Appendix MT1

Thus, the model predicts that to have an inverted U relationship between markups and employee skill levels, the cost and demand effects must be strong. To see why it should be the case, recall that at low levels of $\tilde{x}$, the measure of oligopolies declines if the cost effect for entrants is high enough $\left(\left|\frac{dp(x_{-1}|2\tilde{x}-x_{-1})}{d\tilde{x}}\right| > \left|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\right|\right)$. In addition, it was discussed that at low levels of $\tilde{x}$, the measure of monopolies always increases with higher $\tilde{x}$, as fewer entrants enter due to the cost effect. Together, these imply that, if the cost effect is high enough, the fraction of monopolies should go up for low levels of $\tilde{x}$, which in turn pushes markups up.

For high levels of $\tilde{x}$, I showed that the measure of oligopolies always increases with higher $\tilde{x}$ as exit from oligopolies goes down and entry goes up. However, the measure of monopolies will decline if the demand effect for entrants is strong enough $\left(\left|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\right| > \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}_0}\right)$. Therefore, with strong demand effects, at high levels of $\tilde{x}$, the fraction of monopolies will go down, which will reduce aggregate markups[10].

10. Appendix MT2 illustrates this result numerically by imposing functional forms on $p(x)$ and $g(x)$.

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Appendix for Chapter 1

Appendix ME1

Lemma ME1

Suppose that the firm j's minimization problem is given by:

$$\min_{E_{jt}(X),K_{jt}} \left\{ \int W_t(X)E_{jt}(X)dX + r_t K_{jt} + \lambda_{jt}\Big(Y_{jt} - F(A_{jt}, K_{jt}, L_{jt})\Big) \right\}$$

Then, the first-order conditions of this minimization problem yield the following expression for firm-level markups:

$$\mu_{jt} = \theta_{jt}\left(\frac{P_{jt}Y_{jt}}{B_{jt}}\right)$$

Proof

Taking the first order condition with respect to $E_{jt}(x)$ implies:

$$W_t(X) = \lambda_{jt}\frac{\partial F(\cdot)}{\partial L}\frac{\partial L}{\partial E(X)}$$

Recall the definition of efficiency units of labour:

$$L_{jt} = \int X E_{jt}(X)dX$$

which implies that $\frac{\partial L}{\partial E(X)} = X$. Substituting this into the above expression yields to:

$$\begin{aligned} W_t(X) =& \lambda_{jt} \frac{\partial F(\cdot)}{\partial L} X \\ =& \lambda_{jt} \frac{\partial F(\cdot)}{\partial L_{jt}} \frac{L_{jt}}{F(\cdot)} X \frac{Y_{jt}}{L_{jt}} \end{aligned}$$

Define $\theta_{jt}^L \equiv \frac{\partial F(\cdot)}{\partial L_{jt}} \frac{L_{jt}}{F(\cdot)}$ and multiply both sides of the above expression by $E(X)$:

$$\begin{aligned} W_t(X) E_{jt}(X) &= \lambda_{jt} \theta_{jt}^L \frac{Y_{jt}}{L_{jt}} X E_{jt}(X) \\ \Rightarrow \int W_t(X) E_{jt}(X) dX &= \lambda_{jt} \theta_{jt}^L \frac{Y_{jt}}{L_{jt}} \int X E_{jt}(X) dX \end{aligned}$$

The left-hand side of the above expression is the wage bill, which I denote by B_{jt}. On the right hand side, the terms L_{jt} and $\int X E_{jt}(X) dX$ cancel:

$$B_{jt} = \lambda_{jt} \theta_{jt}^L Y_{jt}$$

Let P_{jt} be the price of output, Y_{jt}. Multiplying and dividing the right hand side by P_{jt} yields to:

$$B_{jt} = \frac{\lambda_{jt}}{P_{jt}} \theta_{jt}^L P_{jt} Y_{jt}$$

Note that, as λ_{jt} is the marginal cost of producing mode output, the expression $\frac{\lambda_{jt}}{P_{jt}}$ is the marginal cost over the price out output, which is the inverse of firm markup:

$$\frac{\lambda_{jt}}{P_{jt}} = \frac{1}{\mu_{jt}}$$

This implies that the expression for markups is given by:

$$\mu_{jt} = \theta_{jt}^L \left(\frac{P_{jt} Y_{jt}}{B_{jt}} \right)$$

Corollary

The expression for markups derived in Lemma ME1 can be expressed as:

$$\mu_{jt} = \theta^L_{jt} \frac{P_{jt} Y_{jt}}{L_{jt}} \frac{\left(\int X dX \right)_{jt}}{\left(\int W_t(X) dX \right)}$$

Proof

Recall the first-order condition of the cost minimization problem:

$$W_t(X) = \lambda_{jt} \theta^L_{jt} \frac{Y_{jt}}{L_{jt}} X$$

Integrating the expression over X and multiplying both sides by P_{jt} implies:

$$\int W_t(X) dX = \frac{\lambda_{jt}}{P_{jt}} \theta^L_{jt} \frac{P_{jt} Y_{jt}}{L_{jt}} \int X dX$$

which implies that markups are given by:

$$\mu_{jt} = \theta^L_{jt} \frac{P_{jt} Y_{jt}}{L_{jt}} \frac{\left(\int X dX \right)_{jt}}{\left(\int W_t(X) dX \right)}$$

Appendix ME2

In this appendix, I illustrate how markups can be derived in a structural model that accounts for firms' monopsony power and workers' choices of which firms to work for. This model closely follows the structural model from Lamadon et al. (2022) .

Worker Preferences

The preferences of each worker i with productivity X_i over working in a firm $j \in \{1, \cdots, J\}$ are described by the following utility function:

$$U_{ijt} = \log\Big(W_{ijt}\Big) + \log\Big(G_j(X_i)\Big) + \lambda^{-1}\varepsilon_{ijt}$$

where $W_{ijt}(X)$ is the wage paid by firm j to worker i with productivity X, $G_j(X_i)$ denotes the value of amenities offered by firm j to worker i, λ is a parameter, and ε_{ijt} denotes the idiosyncratic taste component, which is a worker's private information[11].

The idiosyncratic taste component is assumed to follow a Markov process with independent innovations across individuals. Further, I assume that, for every t, the distribution of $\mathbf{e_{it}} = (\varepsilon_{i1t}, \cdots \varepsilon_{iJt})$ has a nested logit structure, described by:

$$\Phi(\mathbf{e_{it}}) = \exp\Bigg(- \sum_r \Big(\sum_{j \in J_r} \exp\big(- \frac{\varepsilon_{ijt}}{\rho_r}\big)\Big)^{\rho_r}\Bigg)$$

where $r(j)$ denotes the market that firm j operates in, and ρ_r is a measure of the correlation of a worker's preferences across alternative firms in a given market r. It is defined as $\rho_r = \sqrt{1 - corr(\varepsilon_{ijt}, \varepsilon_{iut})}$, for $r(j) = r(u) = r$.

Following Lamadon et al. (2022), I assume that all workers are hired in a spot market. In each period t, a worker observes the wages offered by all firms, $\mathbf{W_t}$, and chooses a firm j to work at to maximize utility $U_{jt}(X)$. The maximization problem yields the following expression for the probability that a worker with productivity X chooses to work at firm j[12]:

$$P[j(i,t) = j | X_i = X, \mathbf{W_t}] = \frac{I_{rt}(X)^{\lambda}}{\sum_{r'} I_{r't}(X)^{\lambda}} \Bigg(G_j(X) \frac{W_{jt}(X)}{I_{rt}(X)} \Bigg)^{\frac{\lambda}{\rho_r}}$$

11. In this model, I abstract from taxes that consumers may face. For a detailed discussion of how taxes impact the utility function and the subsequent solution of the model with taxation, please consult Lamadon et al. (2022)
12. Note that as ε_{ijt} is worker's private information, wages do not depend on idiosyncratic taste parameters.

where

$$I_{rt}(X) = \left(\sum_{j' \in J_r} \Big(G_j(X) W_{j't}(X) \Big)^{\frac{\lambda}{\rho_r}} \right)^{\frac{\rho_r}{\lambda}}$$

Thus, the supply of workers with productivity X that a firm j faces is given by:

$$S_{jt}(X, W) = NM(X) \frac{I_{rt}(X)^{\lambda}}{\sum_{r'} I_{r't}(X)^{\lambda}} \left(G_j(X) \frac{W_{jt}(X)}{I_{rt}(X)} \right)^{\frac{\lambda}{\rho_r}}$$

where $NM(X)$ is the total mass of workers, N, multiplied by the distribution of X, denoted by $M(X)$. Note that the above expression implies the firm-level labour supply elasticity is given by $\frac{\lambda}{\rho_r}$.

Firm's problem

A firm j's production function is given by:

$$Y_{jt} = F(A_{jt}, K_{jt}, L_{jt})$$

where A_{jt} is the technology parameter, K_{jt} denotes the capital stock and L_{jt} is the total efficiency units of labour. Given the demand for workers of productivity X, $D(X)$, the efficiency units of labour is defined as:

$$L_{jt} = \int X D_{jt}(X) dX$$

I assume that firms take the capital rental rate, r_t, as given and they are strategically small in the labour market, which implies that:

$$\frac{\partial I_{rt}(X)}{\partial W_{jt}(X)} = 0$$

Given this, firms choose the amount of the factors of production by minimizing their cost function, subject to the labour market equilibrium condition, $D_{jt}(X) = S_{jt}(X, W)$ and output constraint:

$$\min_{D_{jt}(X), K_{jt}} \left\{ \int W_{jt}(X) D_{jt}(X) dX + r_t K_{jt} \right\}$$

$$\text{s.t.} \quad Y_{jt} - F(A_{jt}, K_{jt}, L_{jt}) = 0$$

$$D_{jt}(X,W) = S_{jt}(X,W) = K_{rt}(X)\Big(G_j(X)W_{jt}(X)\Big)^{\frac{\lambda}{\rho_r}}$$

$$K_{rt}(X) = NM(X)\frac{\Big(I_{rt}(X)\Big)^{\lambda}}{\sum_{r'} I_{r't}(X)^{\lambda}}\left(\frac{1}{I_{rt}(X)}\right)^{\lambda/\rho_r}$$

$$L_{jt} = \int XD_{jt}(X)dX$$

The corresponding Lagrangian is:

$$\text{L} = \int W_{jt}(X)K_{rt}(X)\Big(G_j(X)W_{jt}(X)\Big)^{\frac{\lambda}{\rho_r}}dX + r_tK_{jt} + \phi_{jt}\Bigg(Y_{jt} - F(A_{jt}, K_{jt}, L_{jt})\Bigg)$$

$$\text{s.t.} \quad L_{jt} = \int XK_{rt}(X)\Big(G_j(X)W_{jt}(X)\Big)^{\frac{\lambda}{\rho_r}}dX$$

$$K_{rt}(X) = NM(X)\frac{\Big(I_{rt}(X)\Big)^{\lambda}}{\sum_{r'} I_{r't}(X)^{\lambda}}\left(\frac{1}{I_{rt}(X)}\right)^{\lambda/\rho_r}$$

Taking the first order condition with respect to $W_{jt}(X)$ yields to:

$$K_{rt}(X)G_j(X)^{\lambda/\rho_r}\big(1+\lambda/\rho_r\big)W_{jt}^{\lambda/\rho_r} = \phi_{jt}\frac{\partial F(\cdot)}{\partial L_{jt}}\frac{\partial L_{jt}}{\partial D_{jt}(X)}\frac{\partial D_{jt}(X)}{\partial W_{jt}(X)}$$

$$K_{rt}(X)G_j(X)^{\lambda/\rho_r}\big(1+\lambda/\rho_r\big)W_{jt}(X)^{\lambda/\rho_r} = \phi_{jt}\frac{\lambda}{\rho_r}\frac{\partial F(\cdot)}{\partial L_{jt}}\frac{\partial L_{jt}}{\partial D_{jt}(X)}K_{rt}(X)G_j(X)^{\lambda/\rho_r}W_{jt}(X)^{\lambda/\rho_r - 1}$$

$$\begin{aligned} W_{jt}(X) =& \phi_{jt}\frac{\lambda/\rho_r}{1+\lambda/\rho_r}\frac{\partial F(\cdot)}{\partial L_{jt}}\frac{\partial L_{jt}}{\partial D_{jt}(X)} \\ =& \phi_{jt}\frac{\lambda/\rho_r}{1+\lambda/\rho_r}\frac{\partial F(\cdot)}{\partial L_{jt}}\frac{L_{jt}}{F(\cdot)}X\frac{Y_{jt}}{L_{jt}} \end{aligned}$$

Define $\theta_{jt}^L \equiv \frac{\partial F(\cdot)}{\partial L_{jt}}\frac{L_{jt}}{F(\cdot)}$:

$$W_{jt}(X) = \phi_{jt}\frac{\lambda/\rho_r}{1+\lambda/\rho_r}\theta_{jt}^L\frac{Y_{jt}}{L_{jt}}X$$

Multiply the left and right-hand sides of the above function by (equilibrium) $D_{jt}(X)$ and integrate over X:

$$\int W_{jt}(X)D_{jt}(X)dX = \phi_{jt}\frac{\lambda/\rho_r}{1+\lambda/\rho_r}\theta^L_{jt}\frac{Y_{jt}}{L_{jt}}\int XD_{jt}(X)dX$$

This implies that:

$$B_{jt} = \phi_{jt}\frac{\lambda/\rho_r}{1+\lambda/\rho_r}\theta^L_{jt}Y_{jt}$$

where $B_{jt} = \int W_{jt}(X)D_{jt}(X)dX$ is the wage bill. Define P_{jt} to be the price of output:

$$B_{jt} = \frac{\phi_{jt}}{P_{jt}}\frac{\lambda/\rho_r}{1+\lambda/\rho_r}\theta^L_{jt}P_{jt}Y_{jt}$$

Which implies that the expression for markups ($\mu_{jt} = \frac{P_{jt}}{\phi_{jt}}$) is given by:

$$\mu_{jt} = \frac{\lambda/\rho_r}{1+\lambda/\rho_r}\theta^L_{jt}\frac{P_{jt}Y_{jt}}{B_{jt}}$$

Thus, the only difference between the expression for markups in the main text and the one above is the markdown term, $\frac{\lambda/\rho_r}{1+\lambda/\rho_r}$.

Appendix MT1

Lemma MT1

Demand for product j is given by:

$$y_{jt} = \frac{q_{jt}}{Q_t}\frac{1}{p_{jt}}$$

Proof

Consumer's utility maximization problem is given by:

$$\max_{\{y_{jt}\}_0^F} U_{it} = \int_0^F q_{jt}\ln\left(y_{jt}\right)dj \quad \text{subject to} \quad \int_0^F p_{jt}y_{jt}dj = 1$$

Thus, Lagrangian is:

$$\max_{\{y_{jt}\}_0^F,\lambda} \left\{ \int_0^F q_{jt} \ln \big(y_{jt}\big) dj + \lambda \Big(1 - \int_0^F p_{jt} y_{jt} dj\Big) \right\}$$

The first order conditions are:

$$\frac{q_{jt}}{y_{jt}} = \lambda p_{jt} \quad \text{for each} \quad j$$

$$1 - \int_0^F p_{jt} y_{jt} dj = 0$$

which implies that:

$$\lambda = \frac{\int_0^F q_{jt} dj}{\int_0^F p_{jt} y_{jt} dj}$$

Defining $\int_0^F q_{jt} dj \equiv Q_t$, as the aggregate quality and given that $1 - \int_0^F p_{jt} y_{jt} dj = 0$, we have:

$$\lambda = Q_t$$

The first line of the first order conditions with L mass of consumers imply:

$$y_{jt} = L \frac{q_{jt}}{Q_t} \frac{1}{p_{jt}}$$

Lemma MT2

Suppose the managers' wages are determined as a result of Nash Bargaining (Nash (1950)) and each manager's bargaining power is given by $\beta \in (0, 1)$. Then, the monopolists and the duopolists' net profits are given by:

$$\pi_{jt}^M(x) = L \frac{q_{jt}}{Q_t} \Big(1 - \frac{1}{G}\Big) \Big(1 - \beta\Big) \quad \text{and} \quad \pi_{jt}^D = L \frac{q_{jt}}{2Q_t} \Big(1 - \frac{1}{\Delta}\Big) \Big(1 - \beta\Big),$$

respectively.

Proof

As the bargaining problem is identical in the cases of a monopolist and duopolists, I will only solve the problem for the case of a monopolist.

The Nash Bargaining problem is given by:

$$\max_{W(x)} W(x)^{\beta}\big(\pi_{jt}^{MG}(x) - W(x))\big)^{1-\beta}$$

Taking first order condition:

$$\beta W(x)^{\beta-1}\big(\pi_{jt}^{MG}(x) - W(x))\big)^{1-\beta} - W(x)^{\beta}\big(1-\beta\big)\big(\pi_{jt}^{MG}(x) - W(x))\big)^{-\beta} = 0$$

Solving for $W(x)$ yields to:

$$W(x) = \beta\pi_{jt}^{MG}(x)$$

Thus, the firm's net profits are given by:

$$\pi_{jt}^{M}(x) = \pi_{jt}^{MG}(x) - W(x) = \pi_{jt}^{MG}(x) - \beta\pi_{jt}^{MG}(x)$$

Substituting the expression for gross profits yields to the result:

$$\pi_{jt}^{M}(x) = L\frac{q_{jt}}{Q_t}\Big(1 - \frac{1}{G}\Big)\Big(1-\beta\Big)$$

Lemma MT3

Suppose that the mass of workers is such that $L < \frac{Q}{2\pi_1 \frac{dp(x)}{dx}\frac{dg(x)}{dx}}$ for any x. Then, x_0 declines in both own and rival's manager productivity, and the relationship between x_{-1} and x_1 is U-shaped:

$$\frac{dx_0}{d\underline{x}_0} < 0 \quad \text{and} \quad \frac{dx_0}{d\overline{x}_0} < 0$$

$$\frac{dx_{-1}}{dx_1} < 0 \quad \text{if} \quad x_1 < \left(\frac{\gamma x_{-1}}{\frac{L}{2Q} \frac{dp(x_1)}{dx_1} \frac{dg(x_1)}{dx_1} \pi_0} \right)^{\frac{1}{1-\gamma}}, \quad \text{and} \quad \frac{dx_{-1}}{dx_1} > 0 \quad \text{if} \quad x_1 > \left(\frac{\gamma x_{-1}}{\frac{L}{2Q} \frac{dp(x_1)}{dx_1} \frac{dg(x_1)}{dx_1} \pi_0} \right)^{\frac{1}{1-\gamma}}$$

Proof

For the case of a duopoly, I will demonstrate the proof of $\frac{dx_0}{d\underline{x}_0} < 0$. The proof of $\frac{dx_0}{d\overline{x}_0} < 0$ is identical. Recall the first order condition for oligopolist:

$$\frac{dp(x_0)}{dx_0} \frac{L}{Q_t} g(x_0)\pi_1 + p(x_0) \frac{L}{Q_t} \frac{dg(x_0)}{dx_0} \pi_1 - \frac{dp(x_0)}{dx_0} \frac{L}{Q_t} \left(\frac{g(\overline{x}_0) + g(\underline{x}_0)}{2} \right) \pi_0 - x_0 = 0$$

Fully differentiating the above condition with respect to x_0 and $\underline{x}_0$ yields to:

$$\left[\frac{L}{Q_t} \Big(\frac{d^2p(x_0)}{dx_0^2} g(x_0)\pi_1 + 2\frac{dp(x_0)}{dx_0} \frac{dg(x_0)}{dx_0} \pi_1 + p(x_0) \frac{d^2g(x_0)}{dx_0^2} \pi_1 - \frac{d^2p(x_0)}{dx_0^2} \Big(\frac{g(\overline{x}_0) + g(\underline{x}_0)}{2} \Big) \pi_0 \Big) - 1 \right] dx_0$$
$$- 0.5 \frac{dp(x_0)}{dx_0} \frac{L}{Q_t} \frac{dg(\underline{x}_0)}{d\underline{x}_0} \pi_0 d\underline{x}_0 = 0$$

Thus, we have:

$$\frac{dx_0}{d\underline{x}_0} = \frac{0.5 \frac{dp(x_0)}{dx_0} \frac{L}{Q_t} \frac{dg(\underline{x}_0)}{d\underline{x}_0} \pi_0}{\frac{L}{Q_t} \left(\frac{d^2p(x_0)}{dx_0^2} g(x_0)\pi_1 + 2\frac{dp(x_0)}{dx_0} \frac{dg(x_0)}{dx_0} \pi_1 + p(x_0) \frac{d^2g(x_0)}{dx_0^2} \pi_1 - \frac{d^2p(x_0)}{dx_0^2} \left(\frac{g(\overline{x}_0)+g(\underline{x}_0)}{2} \right) \pi_0 \right) - 1}$$

The expression will be negative, if the denominator is less than zero. As, by assumption, $\frac{d^2p(x)}{dx^2} < 0$ and $\frac{d^2g(x)}{dx^2} < 0$, the denominator can be written as:

$$\frac{L}{Q_t} \Big(- \Big| \frac{d^2p(x_0)}{dx_0^2} \Big| \Big[g(x_0)\pi_1 - \Big(\frac{g(\overline{x}_0) + g(\underline{x}_0)}{2} \Big) \pi_0 \Big] + 2\frac{dp(x_0)}{dx_0} \frac{dg(x_0)}{dx_0} \pi_1 - p(x_0) \Big| \frac{d^2g(x_0)}{dx_0^2} \Big| \pi_1 \Big) - 1$$

First, note it must be the case that $g(x_0)\pi_1 - \left(\frac{g(\overline{x}_0)+g(\underline{x}_0)}{2} \right) \pi_0 > 0$, as otherwise no oligopolist will innovate to become a monopolist. Therefore, for the denominator to be negative, it is sufficient that

$$2\frac{L}{Q_t} \frac{dp(x_0)}{dx_0} \frac{dg(x_0)}{dx_0} \pi_1 < 1$$

which impliies

$$L < \frac{Q_t}{2\pi_1 \frac{dp(x_0)}{dx_0}\frac{dg(x_0)}{dx_0}}$$

which is true, by the assumption of the lemma. Thus, $\frac{dx_0}{d\underline{x}_0} < 0$.

Now, recall the first-order condition for an entrant:

$$\frac{dp(x_{-1})}{dx_{-1}}\frac{L}{Q_t}\left(\frac{g(x_{-1})+g(x_1)}{2}\right)\pi_0 + p(x_{-1})\frac{L}{Q_t}\frac{1}{2}\frac{dg(x_{-1})}{dx_{-1}}\pi_0 - x_{-1}x_1^{\gamma} = 0$$

Similarly, fully differentiating the above expression with respect to x_{-1} and x_1 yields to:

$$\left[\frac{L}{Q_t}\pi_0\Big(\frac{d^2p(x_{-1})}{dx_{-1}^2}\Big(\frac{g(x_{-1})+g(x_1)}{2}\Big)+\frac{dp(x_{-1})}{dx_{-1}}\frac{dg(x_{-1})}{dx_{-1}}+p(x_{-1})\frac{1}{2}\frac{d^2g(x_{-1})}{dx_{-1}^2}\Big) - x_1^{\gamma}\right]dx_{-1}$$
$$+\left[\frac{L}{Q_t}\frac{dp(x_{-1})}{dx_{-1}}\frac{1}{2}\frac{dg(x_1)}{dx_1}\pi_0 - \gamma x_{-1}x_1^{\gamma-1}\right]dx_1 = 0$$

Which implies:

$$\frac{dx_{-1}}{dx_1} = -\frac{\frac{L}{Q_t}\frac{dp(x_{-1})}{dx_{-1}}\frac{1}{2}\frac{dg(x_1)}{dx_1}\pi_0 - \gamma x_{-1}x_1^{\gamma-1}}{\frac{L}{Q_t}\pi_0\left(\frac{d^2p(x_{-1})}{dx_{-1}^2}\left(\frac{g(x_{-1})+g(x_1)}{2}\right)+\frac{dp(x_{-1})}{dx_{-1}}\frac{dg(x_{-1})}{dx_{-1}}+p(x_{-1})\frac{1}{2}\frac{d^2g(x_{-1})}{dx_{-1}^2}\right) - x_1^{\gamma}}$$

First, I will show that the denominator of this expression is negative. Given $\frac{d^2p(x)}{dx^2} < 0$ and $\frac{d^2g(x)}{dx^2} < 0$, it can be written as:

$$\frac{L}{Q_t}\pi_0\Big(-\Big|\frac{d^2p(x_{-1})}{dx_{-1}^2}\Big|\Big(\frac{g(x_{-1})+g(x_1)}{2}\Big)+\frac{dp(x_{-1})}{dx_{-1}}\frac{dg(x_{-1})}{dx_{-1}} - p(x_{-1})\frac{1}{2}\Big|\frac{d^2g(x_{-1})}{dx_{-1}^2}\Big|\Big) - x_1^{\gamma}$$

Therefore, for the denominator to be negative, it is sufficient that

$$\pi_0\frac{L}{Q_t}\frac{dp(x_{-1})}{dx_{-1}}\frac{dg(x_{-1})}{dx_{-1}} < x_1^{\gamma}$$

As $L < \frac{Q_t}{2\pi_1\frac{dp(x_0)}{dx_0}\frac{dg(x_0)}{dx_0}}$ and $\pi_1 > \pi_0$, we have that $L < \frac{Q_t}{\pi_0\frac{dp(x_{-1})}{dx_{-1}}\frac{dg(x_{-1})}{dx_{-1}}}$. Therefore, $\pi_0\frac{L}{Q_t}\frac{dp(x_{-1})}{dx_{-1}}\frac{dg(x_{-1})}{dx_{-1}} < 1$. This is sufficient for $\pi_0\frac{L}{Q_t}\frac{dp(x_{-1})}{dx_{-1}}\frac{dg(x_{-1})}{dx_{-1}} < x_1^{\gamma}$ to hold, as $x_1 > 1$.

Thus, $\frac{dx_{-1}}{dx_1} > 0$ if

$$\frac{L}{Q_t}\frac{dp(x_{-1})}{dx_{-1}}\frac{1}{2}\frac{dg(x_1)}{dx_1}\pi_0 - \gamma x_{-1}x_1^{\gamma-1} > 0 \Leftrightarrow x_1 > \left(\frac{\gamma x_{-1}}{\frac{L}{2Q}\frac{dp(x_1)}{dx_1}\frac{dg(x_1)}{dx_1}\pi_0}\right)^{\frac{1}{1-\gamma}}$$

and $\frac{dx_{-1}}{dx_1} < 0$ if

$$\frac{L}{Q_t}\frac{dp(x_{-1})}{dx_{-1}}\frac{1}{2}\frac{dg(x_1)}{dx_1}\pi_0 - \gamma x_{-1}x_1^{\gamma-1} < 0 \Leftrightarrow x_1 < \left(\frac{\gamma x_{-1}}{\frac{L}{2Q}\frac{dp(x_1)}{dx_1}\frac{dg(x_1)}{dx_1}\pi_0}\right)^{\frac{1}{1-\gamma}}$$

Lemma MT4

The relationship between $\psi_1^D(\tilde{x})$ and $\tilde{x}$ is either U-shaped or it is increasing and convex. The measure of monopolies, $\psi_1^M(\tilde{x})$, has either an inverted-U or increasing and concave relationship with $\tilde{x}$.

Proof

Recall the measure of duopolies at time $t = 1$:

$$\psi_1^D(\tilde{x}) = \psi^D\Big(1 - p(x_0|\tilde{x}) + p\big(x_{-1}|2\tilde{x} - x_{-1}\big)\Big)$$

Differentiating this expression with respect to $\tilde{x}$ yields to:

$$\frac{d\psi_1^D(\tilde{x})}{d\tilde{x}} = \psi^D\Big(-\frac{dp(x_0|\tilde{x})}{d\tilde{x}} + \frac{dp\big(x_{-1}|2\tilde{x} - x_{-1}\big)}{d\tilde{x}}\Big)$$

As it was proved in Lemma MT3, $p(x_0)$ declines in own and rival's manager's productivities. As higher $\tilde{x}$ implies either higher own manager productivity, or higher rival's manager productivity, or both, it must be that:

$$\frac{dp(x_0|\tilde{x})}{d\tilde{x}} < 0$$

In addition, for the case of $p\big(x_{-1}|2\tilde{x}-x_{-1}\big)$, note that, higher $\tilde{x}$ implies higher $\hat{x}_1$ of the incumbent monopolist. As it was shown in Lemma MT3, x_{-1}, and so $p(x_{-1})$, has a U-shaped relationship with the incumbent monopolist's manager productivity. Let $\hat{x}_1^*$ be such that:

$$\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}} < 0 \quad \text{if} \quad \tilde{x} < \hat{x}_1^* \quad \text{and} \quad \frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}} > 0 \quad \text{if} \quad \tilde{x} > \hat{x}_1^*$$

Therefore, for $\tilde{x} > \hat{x}_1^*$ we have that:

$$\frac{d\psi_1^D(\tilde{x})}{d\tilde{x}} = \psi^D\Big(\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| + \Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big|\Big) > 0$$

and for $\tilde{x} < \hat{x}_1^*1$

$$\frac{d\psi_1^D(\tilde{x})}{d\tilde{x}} = \psi^D\Big(\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| - \Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big|\Big)$$

Thus, we have that for $\tilde{x} > \hat{x}_1^*$, the measure of oligopolies is always increasing. For $\tilde{x} < \hat{x}_1^*$, if $\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| < \Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big|$, then it is decreasing, which means overall the relationship between $\psi_1^D(\tilde{x})$ and $\tilde{x}$ is U-shaped. However, if $\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| > \Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big|$, then $\psi_1^D(\tilde{x})$ is increasing for lower values of $\tilde{x}$ as well, but at a lower rate, which implies an increasing-convex relationship

Recall the expression for the measure of monopolies:

$$\psi_1^M(\tilde{x}) = \psi^M\Big(1 - p(x_{-1}|\tilde{x}) + p(\tilde{x}_0|\hat{x}_0)\Big)$$

Differentiating this expression with respect to $\tilde{x}$ yields to:

$$\frac{d\psi_1^M(\tilde{x})}{d\tilde{x}} = \psi^M\Big(-\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}\Big)$$

By assumption on $p(\cdot)$, we have that $\frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}} > 0$. As it was shown in Lemma T3, x_{-1}, and so $p(x_{-1})$, as a U-shaped relationship with $\tilde{x}$. Let x^* be such that:

$$\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} < 0 \quad \text{for} \quad \tilde{x} < x^*, \quad \text{and} \quad \frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} > 0 \quad \text{for} \quad \tilde{x} > x^*$$

Then, for $\tilde{x} < x^*$, we have that:

$$\frac{d\psi_1^M(\tilde{x})}{d\tilde{x}} = \psi^M \Big(\Big| \frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} \Big| + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}} \Big) > 0$$

However, for $\tilde{x} > x^*$:

$$\frac{d\psi_1^M(\tilde{x})}{d\tilde{x}} = \psi^M \Big(- \Big| \frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} \Big| + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}} \Big)$$

Which implies that, if $\Big|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\Big| > \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}$, then $\frac{d\psi_1^M(\tilde{x})}{d\tilde{x}}$ starts to decline and we end up with an inverted-U relationship between $\psi_1^M(\tilde{x})$ and $\tilde{x}$. If, however, $\Big|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\Big| < \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}$, then $\frac{d\psi_1^M(\tilde{x})}{d\tilde{x}}$ still increases, but at a lower rate relative to the case of $\tilde{x} < x^*$, which implies concavity.

Lemma MT5

Suppose that the cost and demand effects for entrants are high, such that:

$$\Big|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\Big| > \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}_0} \quad \text{and} \quad \Big|\frac{dp\big(x_{-1}|2\tilde{x} - x_{-1}\big)}{d\tilde{x}}\Big| > \Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big|$$

Then, the aggregate markups have an inverted U relationship with the average skill levels of managers.

Proof

Recall that the expression for aggregate markups is given by:

$$\overline{\mu}_1(\tilde{x}) = \frac{\psi_1^M(\tilde{x})}{\psi_1^M(\tilde{x}) + \psi_1^D(\tilde{x})} \times \Big(\mu^M - \mu^D\Big) + \mu^D$$

Differentiating it with respect to $\tilde{x}$ yields to:

$$\frac{d\overline{\mu}_1(\tilde{x})}{d\tilde{x}} = \frac{\frac{d\psi_1^M(\tilde{x})}{d\tilde{x}}\psi_1^D(\tilde{x}) - \frac{d\psi_1^D(\tilde{x})}{d\tilde{x}}\psi_1^M(\tilde{x})}{\Big(\psi_1^M(\tilde{x}) + \psi_1^D(\tilde{x})\Big)^2}$$

Substituting the expressions for $\frac{d\psi_1^M(\tilde{x})}{d\tilde{x}}$ and $\frac{d\psi_1^D(\tilde{x})}{d\tilde{x}}$ yields to:

$$\frac{d\overline{\mu}_1(\tilde{x})}{d\tilde{x}} = \frac{\psi^M\psi_1^D(\tilde{x})\Big(- \frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}\Big) - \psi^D\psi_1^M(\tilde{x})\Big(\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| + \frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big)}{\Big(\psi_1^M(\tilde{x}) + \psi_1^D(\tilde{x})\Big)^2}$$

As it is apparent from the above expression, the sign of $\frac{d\overline{\mu}_1(\tilde{x})}{d\tilde{x}}$ depends on the numerator, the sign of which depends on the probabilities of entry. Let $\hat{x}_{11}$ and $\hat{x}_{12}$ be such that

$$\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} < 0 \quad \text{for} \quad \tilde{x} < \hat{x}_{11}, \quad \text{and} \quad \frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}} > 0 \quad \text{for} \quad \tilde{x} > \hat{x}_{11}$$

and

$$\frac{dp\big(x_{-1}|2\tilde{x} - x_{-1}\big)}{d\tilde{x}} < 0 \quad \text{if} \quad \tilde{x} < \hat{x}_{12} \quad \text{and} \quad \frac{dp\big(x_{-1}|2\tilde{x} - x_{-1}\big)}{d\tilde{x}} > 0 \quad \text{if} \quad \tilde{x} > \hat{x}_{12}$$

Without loss of generality, suppose that $\hat{x}_{11} < \hat{x}_{12}$. For $\tilde{x} < \hat{x}_{11}$ we have that:

$$\frac{d\overline{\mu}_1(\tilde{x})}{d\tilde{x}} = \frac{\psi^M\psi_1^D(\tilde{x})\Big(\Big|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\Big| + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}\Big) - \psi^D\psi_1^M(\tilde{x})\Big(\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| - \Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big|\Big)}{\Big(\psi_1^M(\tilde{x}) + \psi_1^D(\tilde{x})\Big)^2}$$

which is positive, given the assumption of $\Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big| > \Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big|$.

Consider $\tilde{x} \in (\hat{x}_{11}, \hat{x}_{12})$. For such values of $\tilde{x}$, $\frac{d\overline{\mu}_1(\tilde{x})}{d\tilde{x}}$ becomes:

$$\frac{d\overline{\mu}_1(\tilde{x})}{d\tilde{x}} = \frac{\psi^M\psi_1^D(\tilde{x})\Big(- \Big|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\Big| + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}\Big) - \psi^D\psi_1^M(\tilde{x})\Big(\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| - \Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big|\Big)}{\Big(\psi_1^M(\tilde{x}) + \psi_1^D(\tilde{x})\Big)^2}$$

By the assumption of strong demand and cost effects for entrants, we have that $\psi^M\psi_1^D(\tilde{x})\Big(- \Big|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\Big| + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}\Big) < 0$ and $-\psi^D\psi_1^M(\tilde{x})\Big(\Big|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\Big| - \Big|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\Big|\Big) > 0$. If the former dominates the latter, then $\overline{\mu}_1(\tilde{x})$ starts declining. However, if the latter positive effect is higher than the former negative, then $\overline{\mu}_1(\tilde{x})$ still increases, but at a lower rate.

Finally, consider $\tilde{x} > \hat{x}_{12}$. For this case, we have that:

$$\frac{d\overline{\mu}_1(\tilde{x})}{d\tilde{x}} = \frac{\psi^M \psi_1^D(\tilde{x})\Big(- \left|\frac{dp(x_{-1}|\tilde{x})}{d\tilde{x}}\right| + \frac{dp(\tilde{x}_0|\hat{x}_0)}{d\tilde{x}}\Big) - \psi^D \psi_1^M(\tilde{x})\Big(\left|\frac{dp(x_0|\tilde{x})}{d\tilde{x}}\right| + \left|\frac{dp\big(x_{-1}|2\tilde{x}-x_{-1}\big)}{d\tilde{x}}\right|\Big)}{\Big(\psi_1^M(\tilde{x}) + \psi_1^D(\tilde{x})\Big)^2}$$

which is negative, by the assumptions of lemma.

Therefore, if the cost and demand effects for entrants are high enough, the aggregate markups and average skill level of managers have an inverted-U shape relationship.

Appendix MT2

To obtain the numerical solution of the model, I assume that the functional forms of $p(x)$ and $g(x)$ are given by:

$$p(x) = \frac{x}{1+x} \quad \text{and} \quad g(x) = x^{\alpha} \quad \text{for} \quad 0 < \alpha < 1$$

Under these assumptions, the profit functions are:

$$\Pi_{-1} = \frac{L}{Q_t}\left(\frac{x_{-1}}{1+x_{-1}}\right)\left(\frac{x_{-1}^{\alpha} + x_1^{\alpha}}{2}\right)\pi_0 - \frac{x_{-1}^2 x_1^{\gamma}}{2}$$

$$\Pi_0 = \frac{L}{Q_t}\left(\frac{x_0}{1+x_0}\right)x_0^{\alpha}\pi_1 + \frac{L}{Q_t}\left(\frac{1}{1+x_0}\right)\left(\frac{\overline{x}_0^{\alpha} + \underline{x}_0^{\alpha}}{2}\right)\pi_0 - \frac{x_0^2}{2}$$

The first order conditions with respect to x_{-1} and x_0 are:

$$\frac{d\Pi_{-1}}{dx_{-1}} = \frac{L}{Q_t}\left(\frac{1}{(1+x_{-1})^2}\right)\left(\frac{x_{-1}^{\alpha} + x_1^{\alpha}}{2}\right)\pi_0 + \frac{L}{Q_t}\left(\frac{x_{-1}}{1+x_{-1}}\right)\frac{\alpha}{2}x_{-1}^{\alpha-1}\pi_0 - x_{-1}x_1^{\gamma} = 0$$

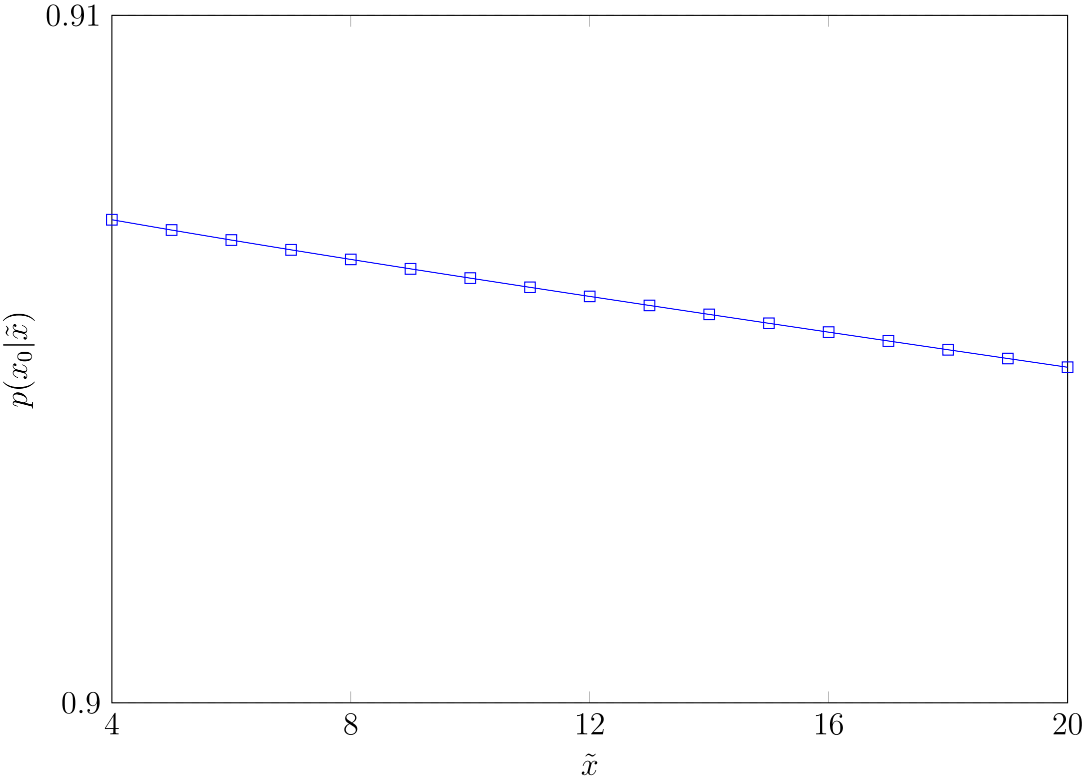
$$\frac{d\Pi_0}{dx_0} = \frac{L}{Q_t}\left(\frac{1}{(1+x_0)^2}\right)x_0^{\alpha}\pi_1 + \frac{L}{Q_t}\left(\frac{x_0}{1+x_0}\right)\alpha x_0^{\alpha-1}\pi_1 - \frac{L}{Q_t}\left(\frac{1}{(1+x_0)^2}\right)\left(\frac{\overline{x}_0^{\alpha} + \underline{x}_0^{\alpha}}{2}\right)\pi_0 - x_0 = 0$$

To numerically solve the model, I assume $\alpha = 0.8$, $\gamma = 0.57$, $G = 5$, $\Delta = 1.5$, and $\frac{L}{Q_0} = 30$. As an example, the values of $\tilde{x}$ are assumed to be ranging from 4 to 20[13].

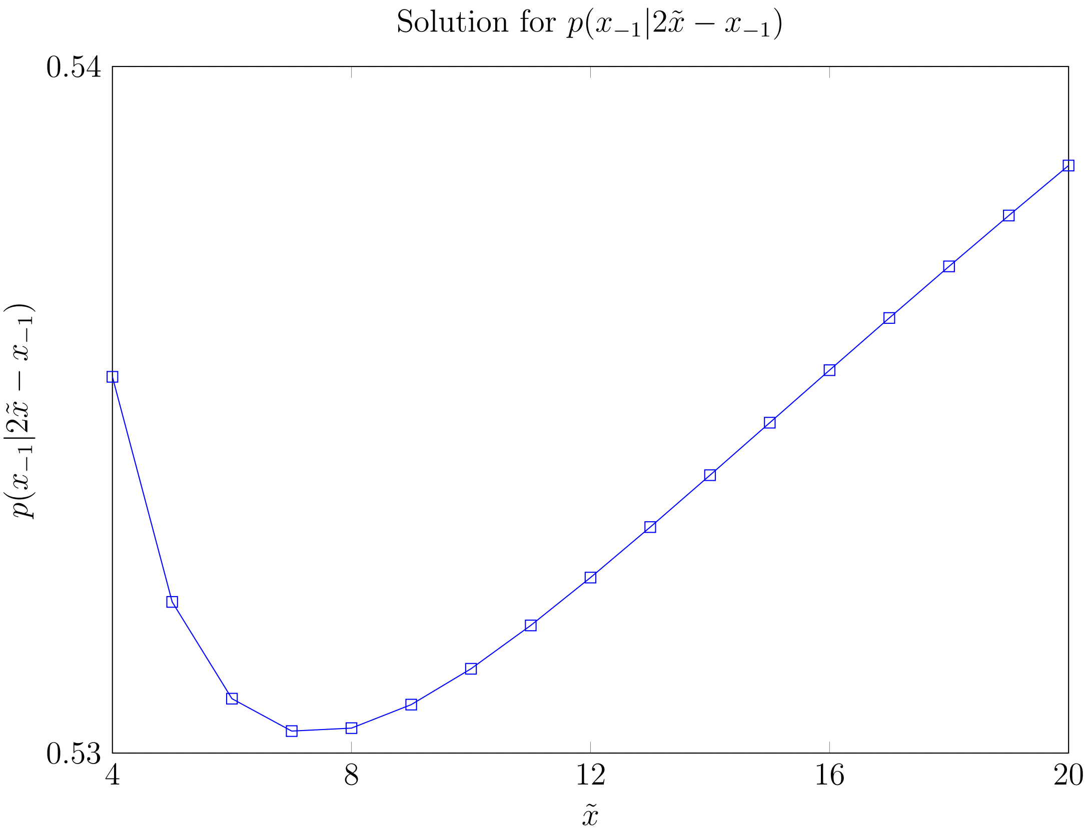
To solve the model, first, I assume $\overline{x}_0 = \underline{x}_0 = \tilde{x}$ and numerically solve for x_0. Then, I set $x_1 = \tilde{x}$ and solve for x_{-1}. Finally, to calculate $p(x_{-1}|2\tilde{x} - x_{-1})$, I numerically solve the first order condition for x_{-1}, with $\frac{x_1 + x_{-1}}{2} = \tilde{x}$ constraint.

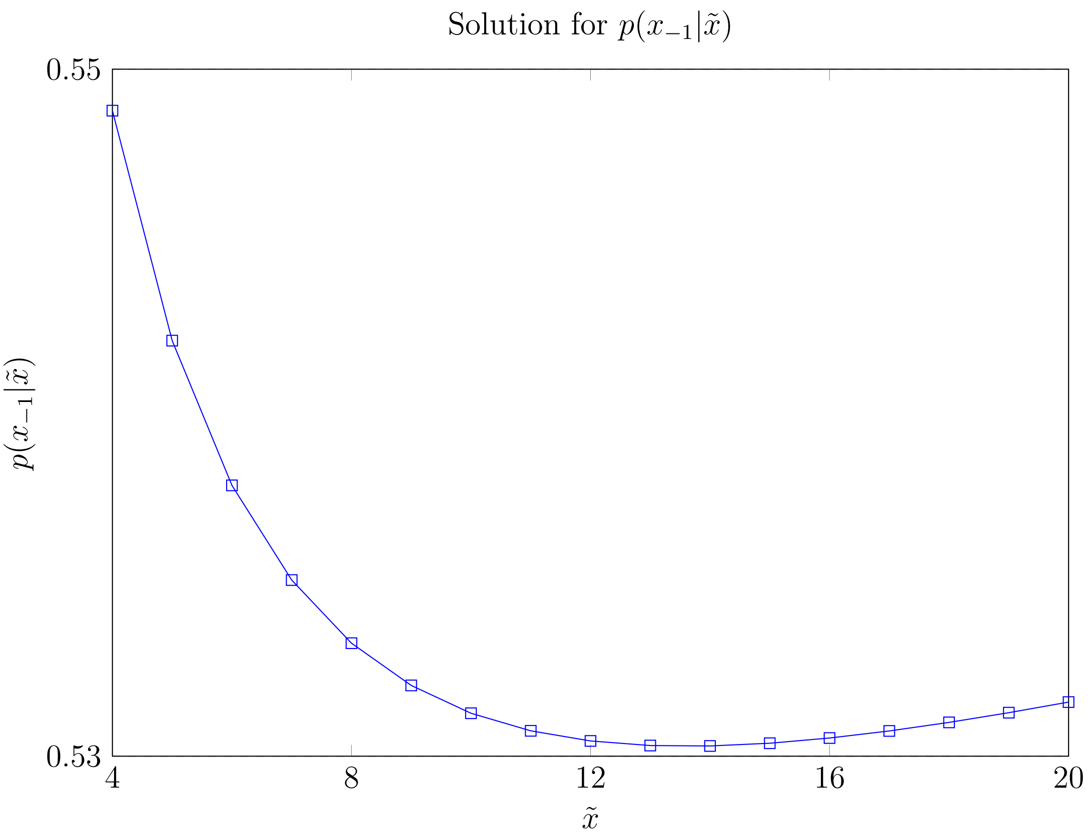
Below I plot the calculated $p(\cdot)$ and aggregate markup functions:

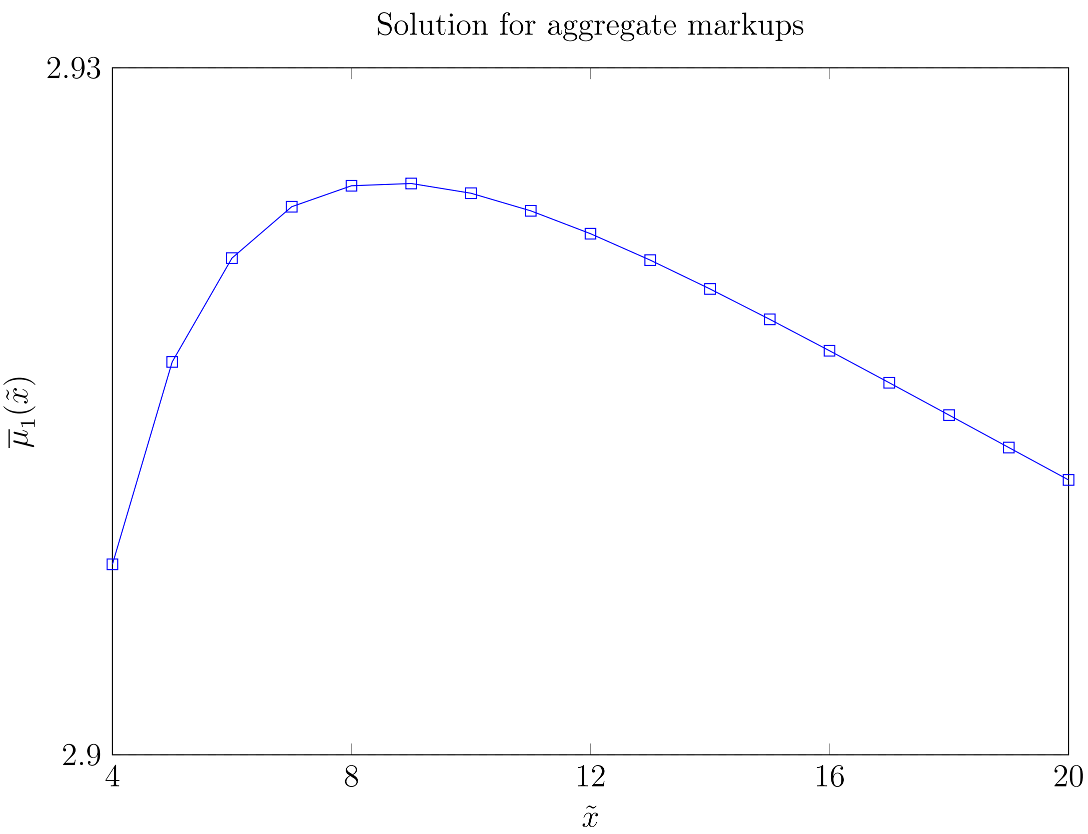
Solution for $p(x_0|\tilde{x})$



13. One can choose any values of $x > 1$, but the parameter values will need to be adjusted according to lemmas' assumptions.


Solution for $p(x_{-1}|2\tilde{x} - x_{-1})$
0.54
0.53
4
8
12
16
20
$\tilde{x}$
$p(x_{-1}|2\tilde{x} - x_{-1})$


Solution for $p(x_{-1}|\tilde{x})$
0.55
0.53
4
8
12
16
20
$\tilde{x}$
$p(x_{-1}|\tilde{x})$


Solution for aggregate markups
2.93
2.9
$\overline{\mu}_1(\tilde{x})$
4
8
12
16
20
$\tilde{x}$

Appendix MF

Figure 1.1: Change of average markups over time

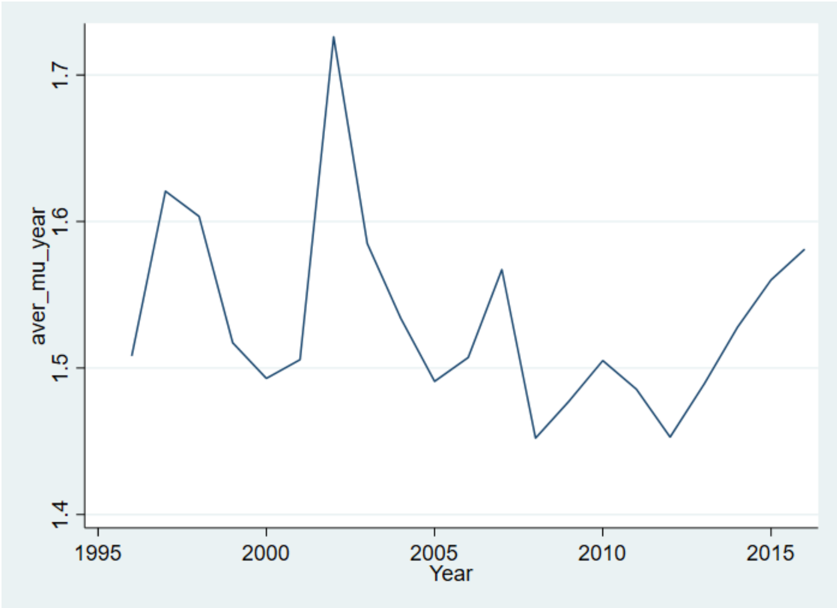


Figure 1.2: Relationship between markups and average worker types

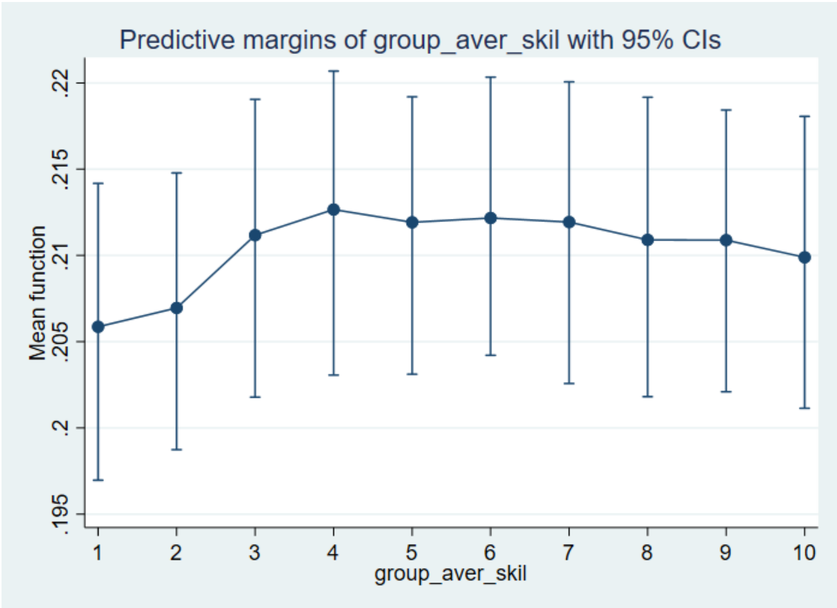
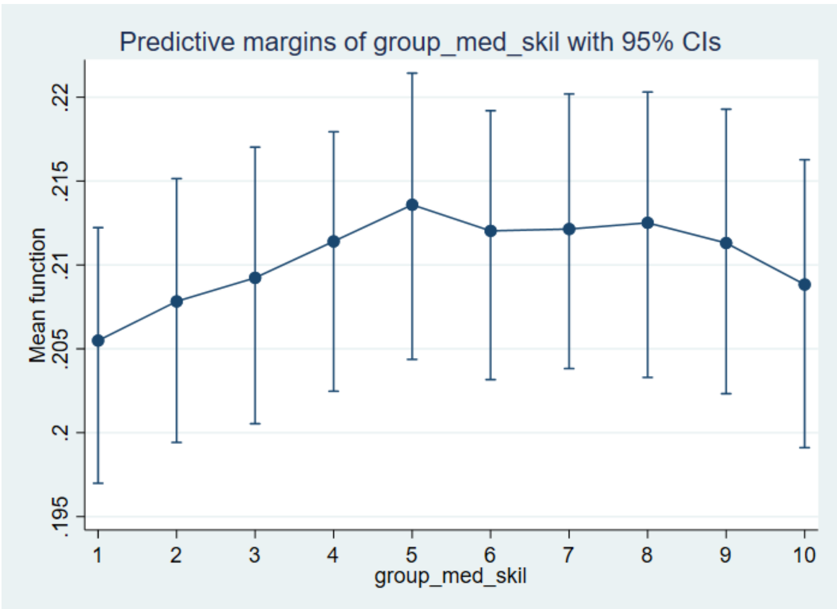


Figure 1.3: Relationship between markups and median worker types



Chapter 2

Exports, Corruption and Innovation

2.1 Introduction

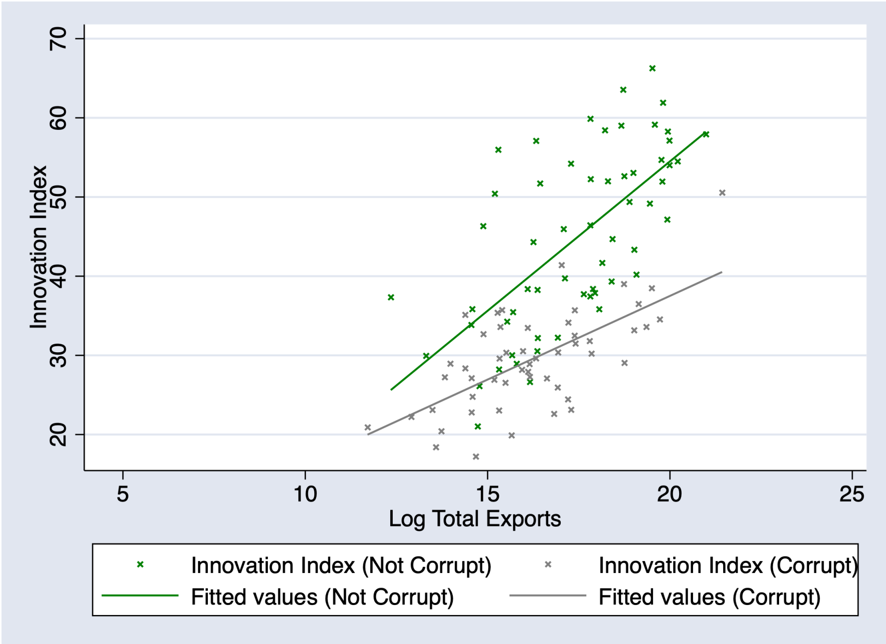
Economists argue that due to higher market size, access to export markets should encourage firms to innovate more[1]. In this paper, I explore whether the country of origin matters for the impact of exports on firm innovation. For example, why do exporter firms originating from Russia and Canada - countries mainly exporting oil and gas with similar total export values[2] - innovate so differently[3]? In this text, I argue that the corruption levels in firms' countries of origin can help to understand why innovations of similar firms from different countries respond differently to the same export demand shocks in the same industries.

To start with, I first consider whether corruption is relevant to the relationship between the aggregate innovativeness of a country and its total exports. Figure 2.1 plots the ranking of countries according to the Global Innovation Index in 2016, produced by the World Intellectual Property Organization[4], against those countries' total exports in the same year[5]. I further divide the countries into "Corrupt" and "Not Corrupt" groups, according to the World Bank's Worldwide Governance

1. Lileeva and Trefler (2010), Grossman and Helpman (1991).
2. According to UN Comtrade (2019)
3. The Global Innovation Index report in 2019 ranked Russia as the 46^{th} and Canada as the 17^{th} most innovative countries among 129 states (Dutta et al. (2019)).
4. Dutta et al. (2016)
5. The relationship holds for different years as well.

Indicators, with countries below the median corruption score marked as "Corrupt" and the countries above the median labelled as "Not Corrupt". For both groups of countries, it seems that countries

Figure 2.1: Correlation between Innovation Index and Total Exports

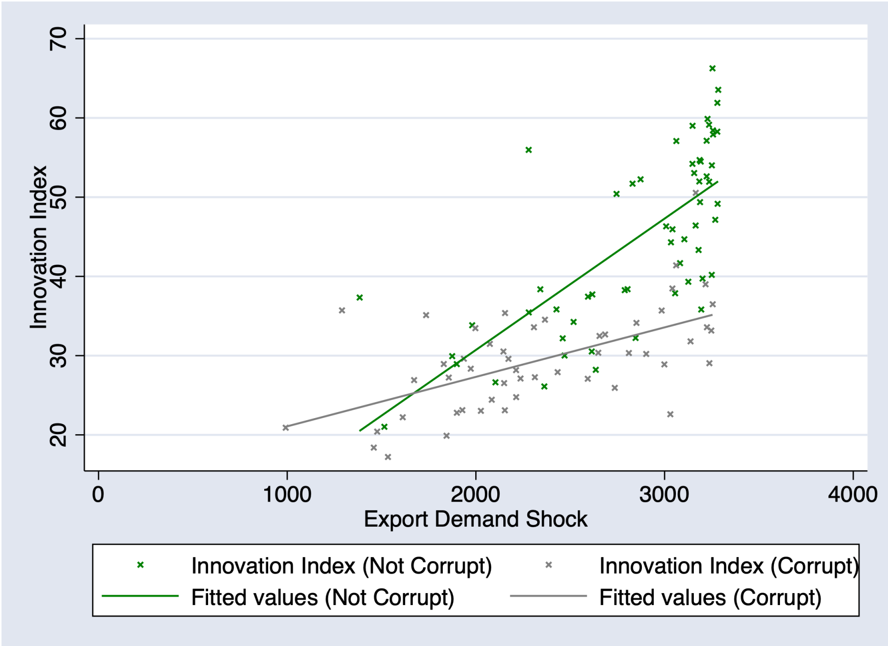


with higher total export values are also the ones with higher innovation index scores. However, for corrupt countries, this relationship seems to be less stark. Moreover, for the same amount of total exports, corrupt countries seem to be less innovative than non-corrupt ones. As can be seen from Figure 2.2, a similar relationship holds if I plot the Global Innovation Index ranking against an exogenous measure of export demand shock[6]. Moreover, Figures 2.3 and 2.4 in Appendix CE illustrate that a similar relationship holds if a country's innovativeness is measured as a percentage of R&D expenditures in GDP. Thus, the preliminary aggregate results suggest that there is a correlation between a country's corruption levels, its innovativeness and exports.

To explore this relationship further on a micro level, in Section 2.2, I develop a theoretical model that explains how corruption in firms' countries of origin may be relevant to the impact of an export demand shock on firms' R&D investments. Following Aghion et al. (2018), I assume that L identical

6. An exogenous export demand shock for a country f is constructed by summing all the (log) exports to that country's export destinations and subtracting f's (log) exports to those destinations from that sum.

Figure 2.2: Correlation between Innovation Index and Exogenous Export Demand Shock



consumers in an export market maximize quadratic utility by choosing the amounts of export and numeraire goods.

The export good is supplied by N firms from different countries that compete á la Cournot in the export market. Further, I assume that only the most efficient firm from each country can export products, and the countries have different corruption levels. Firms are heterogeneous in their marginal costs and invest in R&D to reduce their costs.

Corruption is modelled as artificial entry barriers created by the government of a given country in order to preserve the dominant position of the incumbent exporter firm in that country in exchange for a fixed bribe from the incumbent firm. As a result, due to artificial entry barriers, entrants in corrupt countries face higher marginal costs of production than the ones in non-corrupt countries. This implies that, in corrupt countries, a firm does not need to be very efficient (i.e. have low marginal cost) in order to remain as an incumbent exporter. Consequently, in the export market, exporters from corrupt countries are less efficient (have higher marginal costs) than firms from non-corrupt countries.

Each exporter takes other firms' marginal costs and R&D investments as given and chooses its own R&D levels to reduce its marginal cost. The first prediction of the model is firms from corrupt countries invest significantly less in R&D than the ones from non-corrupt countries.

Regarding the impact of the export demand shock, there are two counteracting effects of an increase in export market size: a positive market size effect and a negative competition effect. The market size effect is the direct result of the increase in export demand, which increases firms' rents and so pushes up investments in R&D. However, as the increase in market size attracts new firms into the export market, the number of firms goes up, which hurts rents and negatively impacts exporters' investments in innovation. This latter effect is called the competition effect. Thus, the overall impact of the increase in export market size can be positive if the market size effect is stronger than the competition effect and negative otherwise.

The equilibrium results indicate that for firms originating from non-corrupt countries, the market size effect is stronger, and the competition effect is weaker than for firms from corrupt ones. Hence, if the market size effect is higher than the competition one for all firms, an increase in R&D investments will be higher for firms originating from non-corrupt countries. If the competition effect dominates the market size one for all firms, the decrease in investments in innovation will be higher for firms originating from corrupt countries. Due to stronger competition and weaker market size effects, it is also possible for R&D investments of firms from corrupt countries to decline/stay the same, but the investments of the ones from non-corrupt states to go up. However, according to the model predictions, it cannot be the case that an increase in export market size increases the R&D investments of firms from corrupt countries and, at the same time, reduces innovation levels of firms from the non-corrupt ones.

In Section 2.4, I test the model predictions empirically. Using the data on corruption from Transparency International, Freedom House, and The World Bank, I construct a measure of corruption for each country for the period of 1996-2020. Following Mayer et al. (2021) and Aghion et al. (2018), I construct a measure of firm-level exogenous export demand shock, using the aggregate trade data from UN Comtrade and the firm-level exports data from Worldscope for firms from 123 countries. Finally, I obtain data on the firm level R&D investments from Worldscope as well.

I estimate the relationship between corruption, trade and R&D investments using the fixed-effects regression approach. I estimate several different specifications of the model by controlling for firm, industry, country of origin, export destination fixed effects and their interactions. The empirical results confirm the theoretical predictions. I find that, on average, firms from non-corrupt countries invest around 8 times more into R&D than the ones from corrupt states. Moreover, the export demand shock is found to be positively associated with R&D investments of firms originating from non-corrupt states. However, I do not find a statistically significant association between the export shocks and R&D investments of firms from corrupt countries.

This chapter is organized as follows. Section 2.2 develops the theoretical model. Section 2.3 describes the data sources. Finally, Section 2.4 discusses the estimation procedures and presents empirical results.

2.2 Model

In this section, I present the theoretical model that analyzes how export demand shock impacts firms' innovation incentives, depending on the corruption levels in the countries where the firms originate from. The model follows closely the one in Mayer et al. (2014) and Aghion et al. (2018), augmented with corruption. I consider some export destination D occupied by L consumers, each consuming exported products and a numeraire good. N firms from different countries with different corruption levels export their goods to D and compete á la Cournot. Firms differ in their marginal costs and baseline efficiency levels. The baseline efficiency levels depend on which country a given firm originates from. Marginal costs are determined as a result of R&D investments that firms undertake to reduce their marginal costs.

2.2.1 Consumers

There are $L > 1$ consumers. Each consumer maximizes utility by choosing the amounts of the numeraire good, M, and the export good, X. A consumer j has a quadratic utility function given by:

$$U_i(M, X) = \beta M + \alpha X - \frac{1}{2}X^2$$

where $\alpha > 0$ and $\beta > 0$[7]. A representative consumer maximizes the above utility function, subject to budget constraint $M + p_X X = 1$, where, for simplicity, I assumed that each consumer's income level equals one. A representative consumer's maximization problem is given by:

$$\max_{M,X} \beta M + \alpha X - \frac{1}{2}X^2 \quad \text{subject to} \quad M + p_X X = 1$$

I will only consider the interior solution, which implies that the demand of a representative consumer for exported goods is given by[8]:

$$p_X = \frac{\alpha - X}{\beta}$$

2.2.2 Firm optimization

I assume that only the most efficient firm from a given country can export products. That is, there is one exporter firm from each country[9]. In addition, all exporter firms supply a homogenous product. Thus, it implies that

$$X = \sum_{j}^{N} x_j^{f(j)}$$

where $x_j^{f(j)}$ is the amount supplied by a firm j from country $f(j)$ to one consumer. Firms exporting to destination D compete á la Cournot-simultaneously choose quantities to maximise profits:

$$\max_{x_j^{f(j)}} \left\{ L x_j^{f(j)} \left(\frac{\alpha - \left(\sum_{j' \neq j}^{N-1} x_{j'}^{f(j')} \right) - x_j^{f(j)}}{\beta} \right) - c_j^{f(j)} x_j^{f(j)} L \right\}$$

7. The assumption of a quadratic utility function is made for mathematical convenience. The model can easily be extended to a more general class of utility functions.

8. I assume that α is large enough, so that $\alpha > X$, for any X.

9. This assumption implies that firms have to enter the domestic market first in order to be exporters. Hence, the most efficient firm in a given country will be the monopolist in the domestic market, and so that firm will be the exporter. In this chapter, I abstract from modelling the demand in the domestic market, as it would overcomplicate the model unnecessarily, without much insight in return.

where $c_j^{f(j)}$ is the marginal cost of firm j from country f. Appendix CT, Lemma C1 shows that, in equilibrium, the quantity that a firm j from a country f supplies is given by:

$$x_j^{f(j)} = \frac{\alpha + \beta \sum_j^N c_j^{f(j)}}{N+1} - \beta c_j^{f(j)}$$

and the equilibrium profits of firm j are given by:

$$\pi_j^{f(j)} = L\left[\frac{\left(\alpha + \beta \sum_j^N c_j^{f(j)} - \beta(N+1)c_j^{f(j)}\right)^2}{\beta(N+1)^2}\right] \tag{2.1}$$

2.2.3 Corruption

I model corruption as artificial entry barriers created by the government of a given country in order to preserve the dominant position of the incumbent exporter firm in that country. More precisely, if some country $f(j)$ is corrupt, then the current incumbent exporter j from that country limits potential entry from the entrants in that country in exchange for paying some fixed fee (bribe) $0 \leq B^{f(j)} \leq \pi_j^{f(j)}$ to that country's officials.

In return, the officials create entry barriers for the entrants, which translates into higher marginal costs for potential entrants. That is, if in the absence of corruption, an entrant's marginal cost of production would be $c_e^{f(j)}$, then because of the artificial entry barriers, this cost rises to $\left(c_e^{f(j)}\gamma^{f(j)}\right)$, for $\gamma^{f(j)} \geq 1$. Consequently, corruption makes entry less profitable for entrants. Moreover, I assume that the higher the fixed bribe, $B^{f(j)}$, the higher the value of $\gamma^{f(j)}$.

Note that $\gamma^{f(j)} = 1$ implies that the country $f(j)$ is completely free of corruption. Therefore, at $\gamma^{f(j)} = 1$, it must be that $B^{f(j)} = 0$. Higher $\gamma^{f(j)}$ implies: 1) more artificial barriers to entry, 2) higher $B^{f(j)}$, and so 3) a higher corruption level in $f(j)$.

2.2.4 Baseline cost

A firm j from country $f(j)$ is characterised by its baseline marginal cost, denoted by $\tilde{c}_j^{f(j)}$. I define the baseline cost as the maximum cost that enables firm j to remain as the most efficient firm in

$f(j)$ and so export products. Let $\overline{c}_e^{f(j)}$ be the marginal cost (in the absence of corruption) of the most efficient entrant that the incumbent exporter j faces in $f(j)$. Then, given the level of $\gamma^{f(j)}$, the maximum cost that enables the firm j to remain as the incumbent exporter is:

$$\tilde{c}_j^{f(j)} = c_e^{f(j)} \gamma^{f(j)}$$

Thus, a firm's baseline marginal cost is increasing in corruption level in the country of origin. Intuitively, because of artificial entry barriers that keep domestic rivals out of the market, a firm originating from a corrupt country doesn't need to have a high baseline efficiency (lower baseline marginal cost) in order to become an exporter from that country.

For simplicity of the analysis, I assume that the most efficient entrants from all countries have the same marginal costs in the absence of corruption. More precisely, I assume that $\overline{c}_e^{f(j)} = \overline{c}_e \quad \forall f(j)$. This assumption implies that the firms' baseline marginal costs are given by:

$$\tilde{c}_j^{f(j)} = c_e \gamma^{f(j)} \tag{2.2}$$

2.2.5 Innovation

In order to capture a larger share of the export market, exporter firms invest in R&D to reduce their baseline marginal cost. More formally, I assume that a firm's marginal cost is determined by:

$$c_j^{f(j)} = \tilde{c}_j^{f(j)} - \varepsilon_j^{f(j)}$$

where $\varepsilon_j > 0$ is the firm j's R&D investment level, and $\tilde{c}_j^{f(j)}$ is defined as in (2.2). Following the literature, I assume that the cost of innovation is quadratic and is given by $\frac{\left(\varepsilon_j^{f(j)}\right)^2}{2}$.

A firm j takes the number of firms, N, market size, L, and the cost levels of all other firms,

$\sum_{j'\neq j}^{N-1} c_{j'}^{f(j')}$, as given and chooses $\varepsilon_j^{f(j)}$ to maximize profits, given in (2.1):

$$\max_{\varepsilon_j^{f(j)}} \left\{ L\left[\frac{\left(\alpha + \beta \sum_{j'\neq j}^{N-1} c_{j'}^{f(j')} - \beta N\left(\tilde{c}_j^{f(j)} - \varepsilon_j^{f(j)}\right)\right)^2}{\beta(N+1)^2}\right] - \frac{\left(\varepsilon_j^{f(j)}\right)^2}{2} - B^{f(j)} \right\}$$

Appendix CT, Lemma C2 shows that the first order condition for $\varepsilon_j^{f(j)}$ yields to:

$$\varepsilon_j^{f(j)} \frac{1}{2}\left(\frac{\left(N+1\right)^2}{N}\right) - L\beta c_e\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')} - \gamma^{f(j)}\right)\right)\left(\frac{N+1}{N+1-2\beta LN}\right) = L\left(\alpha - \beta c_e \gamma^{f(j)}\right) + L\beta\varepsilon_j^{f(j)} \tag{2.3}$$

which implies that the expression for the profit-maximizing value of $\varepsilon_j^{f(j)}$ is given by:

$$\varepsilon_j^{f(j)} = \frac{2LN\left(\alpha - \beta c_e \gamma^{f(j)}\right) + L\beta c_e\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')} - \gamma^{f(j)}\right)\right)\left(\frac{N+1}{N+1-2\beta LN}\right)}{\left(\left(N+1\right)^2 - 2LN\beta\right)} \tag{2.4}$$

Thus, a firm j's R&D investments depend on the export market size, L, number of exporting firms, N, corruption levels in the country of origin, $\gamma^{f(j)}$, and on how the corruption level in the country of origin compares to the corruption levels of all other exporting firms' countries, $\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')} - \gamma^{f(j)}\right)\right)$.

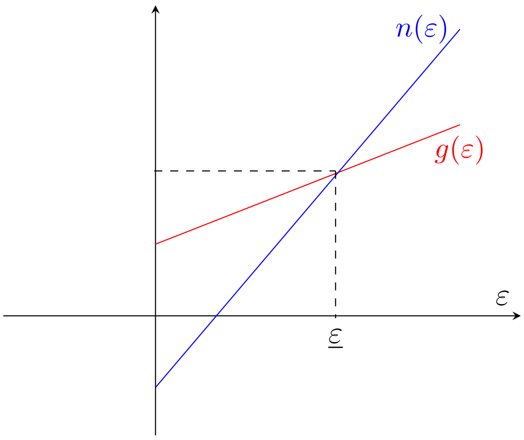
2.2.6 The role of corruption in determining R&D

To understand how corruption impacts a firm's R&D investments, note that a firm's output choice in Cournot model depends negatively on all other firms' production levels and so positively on their baseline marginal costs. In this model, firms that originate from the least corrupt countries are the most efficient ones with low baseline marginal costs. Thus, if a firm j's country of origin is more corrupt relative to rivals' countries, it implies that the firm j's marginal cost is higher than the rivals'. As a result, the firm j will be capturing a lower share of the market and, therefore, have lower profits. However, smaller profits mean that the firm j's incentives to invest in R&D are low.

To illustrate this graphically, below I will plot the equilibrium condition from (2.3)[10]. First, consider the firm that originates from the least corrupt country, with corruption level $\underline{\gamma} < \gamma^{f(j')} \quad \forall f(j')$. This implies that

$$\sum_{j' \neq j}^{N-1} \left(\gamma^{f(j')} - \underline{\gamma}\right) > 0$$

Define $g(\varepsilon)$ as the right-hand side of (2.3), and $n(\varepsilon)$ to be the left-hand side of the expression. The equilibrium value of $\varepsilon_j^{f(j)}$ is determined as a result of the intersection of these two functions:



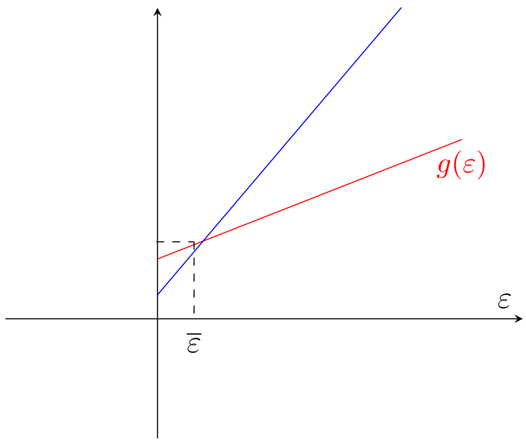
Now, consider a firm originating from the most corrupt country, with the corruption level $\overline{\gamma} > \gamma^{f(j')} \quad \forall f(j')$. For such a firm, it must be true that:

$$\sum_{j' \neq j}^{N-1} \left(\gamma^{f(j')} - \overline{\gamma}\right) < 0$$

In this case, the intercept of $n(\varepsilon)$ is always positive, and the intercept of the $g(\varepsilon)$ is lower than the previous case[11]:

10. Note that to guarantee that the equilibrium level of $\varepsilon_j^{f(j)}$ is non-negative, I assume β to be such that $\frac{1}{2}\left(\frac{N+1}{N}\right)^2 > L\beta$, and α to be such that $\alpha > \beta c_e \gamma^{f(j)} \quad \forall f(j)$.

11. In addition to the previous assumptions, for a non-negative equilibrium value of ε to exist, in this case it has to be that $L\left(\alpha - \beta c_e \gamma^{f(j)}\right) \geq L\beta c_e \left| \sum_{j' \neq j}^{N-1} \left(\gamma^{f(j')} - \overline{\gamma}\right) \right| \left(\frac{N+1}{N+1-2\beta LN}\right)$. Otherwise, the lines will not cross, and so no positive ε for such $\overline{\gamma}$ exists.



As can be seen from the graph above, the R&D investments of a firm originating from the most corrupt country are lower than the investments of a firm from the least corrupt country. Thus, higher corruption levels in the country of origin impact R&D investments negatively.

2.2.7 Free entry into export market

I close the model by assuming free entry into the export market. This implies that firms will enter the export market until profits are generated equal to the fixed bribe. That is if a firm $\hat{j}$ from a country with corruption level $(\hat{\gamma}, \hat{B})$ is the marginal firm, then it must be the case that:

$$\pi\Big(L, N, \sum_{j'\neq j}^{N-1}\big(\gamma^{f(j')}\big), \hat{\gamma}, \sum_{j'\neq j}^{N-1}\big(\varepsilon^{f(j')}\big), \hat{\varepsilon}\Big) = \hat{B} \tag{2.5}$$

Thus, a firm from a country with corruption levels $\gamma^f < \hat{\gamma}$ will not find it profitable to enter[12].

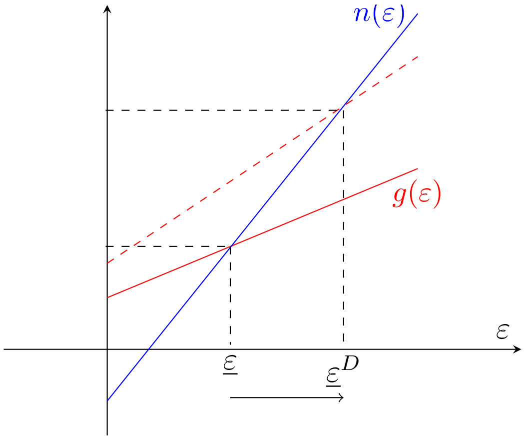
By virtue of the envelope theorem, it can be shown that π increases in L and decreases in N. Thus, for (2.5) to hold, if L goes up, it must be that N goes up too. That is, if the export market size goes up, firms from even more corrupt countries will find it profitable to enter. This, in turn, will increase the right-hand side of (2.5) as well until equality is restored, as the new entrants, by construction, will be from more corrupt countries.

12. Note that, in the example of the firm from the most corrupt country in the previous section, it must be that $\overline{\gamma} = \hat{\gamma}$.

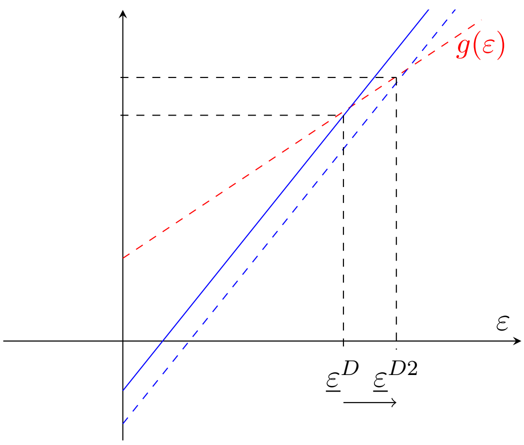
2.2.8 Impact of export market size

In this section, I will analyze how an increase in the export market size, L, impacts firms' innovation incentives, depending on the corruption levels of the countries that they originate from. I will first start from a firm that originates from a relatively non-corrupt country so that $\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')}-\gamma^{f(j)}\right)\right)>0$. Without loss of generality, consider the firm from the least corrupt country, as in Section 2.2.6.

First, consider the function $g(\varepsilon)$. An increase in L tilts this function upward and also shifts it up:

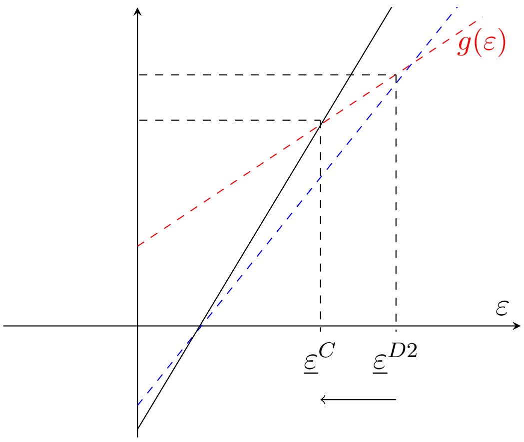


Now consider the $n(\varepsilon)$ function. The direct effect of the increase in L is to shift this function downward, as $\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')}-\gamma^{f(j)}\right)\right)>0$:



Thus, as can be seen from the above graphs, the direct effect of the increase in L is positive. I call this positive effect as the *market size effect*.

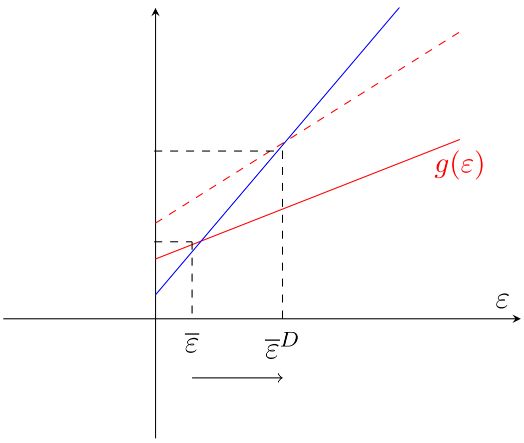
As (2.5) implies, because of the free entry into the export market, if the export market size goes up, more firms will enter the market. Thus, N will increase as well. An increase in N does not impact the $g(\varepsilon)$ function. However, it makes the $n(\varepsilon)$ function steeper, which counteracts the positive direct effect. This is called the *competition effect*. However, because $\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')}-\gamma^{f(j)}\right)\right)>0$, an increase in N also shifts the $n(\varepsilon)$ curve downward, which mitigates the negative competition effect.



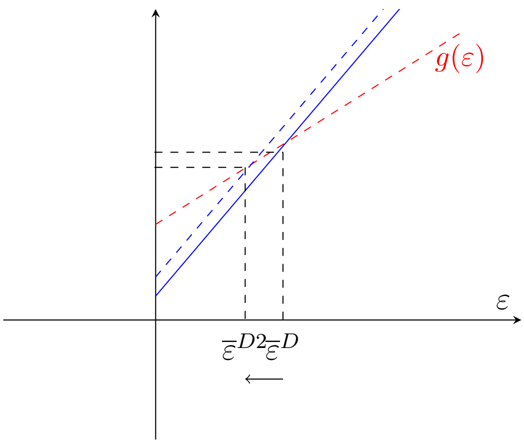
To sum, an increase in market size has two opposite effects for firms from less corrupt countries (efficient firms). The first one is the direct effect of an increase in market size, which increases innovation incentives. Moreover, this positive effect is large for efficient firms. However, an increase in market size attracts new entrants to the export market and so raises competition. The direct effect of the increase in competition is negative on the firms' R&D levels. However, because the increase in N also reduces the rivals' incentives to innovate, there is also a positive impact of the increase in the number of firms for efficient firms. Therefore, I can conclude that, for firms originating from less corrupt countries, the market size effect is strong, and the competition effect is weak.

Now, consider the impact of an increase in market size for firms originating from corrupt countries: $\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')}-\gamma^{f(j)}\right)\right)<0$. As before, without loss of generality, consider the firm from the most corrupt country.

Consider the $g(\varepsilon)$ function. As before, an increase in L makes this function steeper and also shifts it up. However, as $\overline{\gamma}$ is high, the shift is lower than in the case of the least corrupt firm.

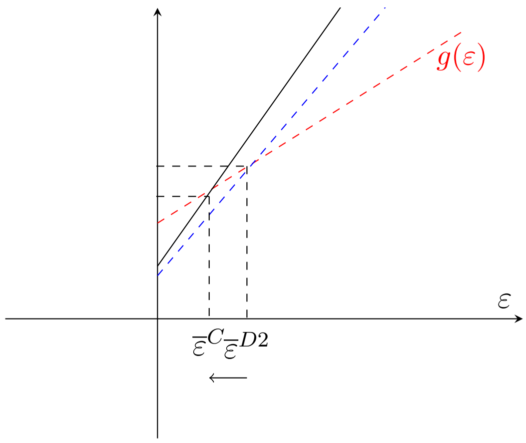


At the same time, because $\left(\sum_{j'\neq j}^{N-1}\left(\gamma^{f(j')}-\gamma^{f(j)}\right)\right)<0$, an increase in L shifts the $n(\varepsilon)$ curve up



This latter effect counteracts the first positive effect of an increase in L. The reason is that because an increase in L also pushes up the rival firms' investments in R&D, it discourages the inefficient firms from corrupt countries from innovating.

As before, an increase in N makes the $n(\varepsilon)$ curve steeper, which pushes down the R&D investments due to the competition effect. At the same time, it pushes up the $n(\varepsilon)$ curve, reducing ε even more. That is, the model predicts that for firms originating from corrupt countries, due to them being less efficient relative to other firms, the competition effect is more severe.



As is the case for firms originating from non-corrupt countries, an increase in export market size has two counteracting effects for inefficient firms from corrupt countries: market size and competition effects. However, the magnitudes of these effects are different. The market size effect is lower, and the competition effect is larger for inefficient firms.

The overall impact of an increase in export market size on ε can be either positive or negative for either firm type, depending on the magnitudes of the market size and competition effects. If the overall effect is positive for both firm types, then firms originating from non-corrupt countries will experience a much larger increase than the firms originating from corrupt countries. This is due to stronger market size and weaker competition effects for firms from non-corrupt countries. Likewise, if the overall impact is negative, then the decrease in the R&D investments of firms from non-corrupt countries will be much lower. Due to strong competition and weak market size effects, it is also possible for R&D investments of firms from corrupt countries to decline, but the investments of the ones from non-corrupt states to go up. However, according to the model predictions, it cannot be the case that an increase in export market size increases the R&D investments of firms from corrupt countries and, at the same time, reduces innovation levels of firms from the non-corrupt ones.

In the remainder of the paper, I test these predictions empirically.

2.3 Data sources

In this section, I describe the data sources used in the empirical analysis. I use country-level datasets on corruption and trade flows and firm-level data on several balance sheet items of firms from different countries.

2.3.1 Corruption data

I use corruption indexes constructed by three different organizations: Transparency International, Freedom House and The World Bank.

Transparency International's Corruption Perception Index (CPI) was established in 1995 and ranks countries based on a $0-100$ scale, with a higher number corresponding to lower corruption. CPI is based on 13 data sources that assess corrupt behaviours in the public sector and mechanisms available to prevent corruption, such as bribery, diversion of public funds, the effective prosecution of corrupt officials, etc. There were methodological changes introduced to CPI measure in 2012. For the consistency of the measure, I focus on CPI data from 2012 only.

Freedom House's "Freedom in the World" annual report numerically rates countries on political rights and civil liberties since 1978. The report is produced each year by a team of analysts from academic, think-tank and human rights communities using sources from academic analyses, news articles, etc. One of the questions that the experts rank countries on asks: "Are safeguards against official corruption strong and effective?". The report ranks countries based on a scale of $0-4$ based on this question, with a higher ranking meaning stronger anti-corruption measures. I use the ranking based on this question as a corruption measure from Freedom House. The data for this ranking is available for the period of $2013-2020$.

The World Banks's "Worldwide Governance Indicators" (WGI) has been annually producing indexes for over 200 countries on six dimensions of governance since 1996, which include "Regulatory Quality", "Rule of Law", "Control of Corruption" etc. Information from over 30 underlying data sources is aggregated using the Unobserved Components Model in order to produce the indicators.

For the empirical analysis of this paper, I use the control of corruption index, which "...captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests."[13]. The index ranges from -2.5 to 2.5, with higher values corresponding to lower corruption.

2.3.2 Firm level data

I obtain the information on firm-level R&D investment from the **Worldscope** dataset provided by Thomson Reuters. The data coverage starts from 1980 and provides information on financial statements of firms from across the world. The dataset primarily covers publicly traded firms, which generates questions about the representativeness of the sample. However, given that the firms included in the sample represent approximately 95% of global market capitalization, it provides a solid coverage of economic activity around the world on a firm level.

As the earliest corruption data that I have dates to 1996 and the latest is from 2020, I extract the firm-level information from Worldscope for the period of 1996-2020. This extract has around 1.3 million firm-year observations, which includes $108,000$ unique firms from 162 countries.

From this dataset, I use information on firms' R&D investments and revenues from foreign geographical regions, which is used to construct the trade shock variable described below. The information on R&D investments is not available for most firms in the dataset. I drop all the missing values for R&D and focus on firms that have invested at least once into R&D. I further restrict the sample to countries from which there are at least 50 firms in the sample in a given year. After these sample restrictions, there are $354,304$ sample points from 123 countries remaining in the data. The distribution of firms across countries can be found in Table 2.1 in Appendix CE.

13. The quote is taken from the "Documentation for the World Governance Indicators", which can be accessed at https://www.worldbank.org/en/publication/worldwide-governance-indicators/documentation.

2.3.3 Aggregate trade data

I obtain the aggregate statistics of imports and exports on the country level from the **World Bank's "World Integrated Trade Solutions" (WITS)**. The WITS allows access to data on bilateral trade and tariffs in U.S. dollars from the UN Comtrade and UNCTAD Trade Analysis Information System for over 180 countries. I use the data on country-level exports from this dataset in order to construct the export shock variable, which will be discussed in the next section.

2.4 Empirical specification and results

In this section, I first describe the measures of corruption and firm-level export shock variables. Then, I describe the empirical strategies used to estimate the relationship between export shocks and firms' R&D investments, followed by the results.

2.4.1 Corruption indicator

To construct the corruption indicator, I first standardise the corruption indexes from all three sources. In each corruption data source, I subtract the mean of corruption indexes in a given year from a given country's assigned corruption index and divide it by the standard deviation. The pairwise correlation between two standardised corruption indexes from any two sources is at least 0.86. The Cronbach's Alpha, which indicates how well the three indexes form a single scale measuring same concept, is 0.9548[14].

Let $c_f \in \{0, 1\}$ be an indicator variable that takes a value of 1 if a country f is *not* corrupt, and it equals 0 otherwise. Given that in all three corruption data sources a higher index indicates a lower corruption level, I define a country f as corrupt at time t ($c_{ft} = 0$) if the standardized scores from all three sources are negative. If not all three indexes are available, I define a country as corrupt if the available indexes are negative. That is, if, say, in a given year, only the index from the World

14. A rule of thumb is the Cronbach's Alpha above 0.8 is considered to be sufficient to conclude that the indexes measure the same concept.

Bank is available for some country f, then I define that country as corrupt if the standardized corruption index from the World Bank is negative. Likewise, if the indexes are positive, then I define the country as being not corrupt ($c_{ft} = 1$).

Using this definition, around 58% of the sample points in the corruption data are defined to be "corrupt" and 42% "not corrupt". Around 30% of the sample points belong to countries that always remain "not corrupt", and 35% of the sample points are from countries that always remain "corrupt" during the sample period. Thus, the rest of the data points belong to countries that experience a change in their corruption status.

2.4.2 Firm level export shock

I closely follow Aghion et al. (2018) and Mayer et al. (2021) in constructing the exogenous export shock on the firm level. Consider a firm j from country f with total exports at time t denoted by X_{jft} and total sales S_{jft}. Further, let M_{dt}^{f} denote the total exports to country d, except for country f's exports to d. As it is argued in Aghion et al. (2018), by subtracting the country f's exports from the total imports of destination d, I aim to exclude the sources of variation that originate from country f that may impact country f's firms. Given these, I construct the exogenous export demand shock that a firm j in country f faces at time t as:

$$E_{jft} = \frac{X_{jft_0}}{S_{jft_0}} \sum_{d} \log\left(M_{dt}^{f}\right) \tag{2.6}$$

where X_{jft_0}/S_{jft_0} denotes the firm j's exports as a fraction of total sales at the initial time period in the sample, which measures the importance of exports in firm j's sales. $\sum_d \log\left(M_{dt}^{f}\right)$ is the sum of all imports in all destinations that a country f's firms export to, except for the exports from country f to those destinations. Using this definition, around 54% of the firms in the sample are exporters, and the rest do not export. Furthermore, around 74% of all exporters operate in manufacturing sectors. Therefore, following Aghion et al. (2018), for the rest of the analysis, I will focus on manufacturing firms only[15].

2.4.3 The relationship between corruption and innovation

Equipped with the measure of corruption, I now proceed to test the first prediction of the model, which states that the firms originating from corrupt countries should have lower R&D levels than the firms originating from countries with low corruption levels.

The average of R&D investments of manufacturing firms from corrupt countries over the whole sample is around 8 times less than the average of firms from non-corrupt ones. I test whether this difference between the average R&D investments significantly differs from zero. The value of the t-statistic of this test is -21.5, which suggests that the difference is statistically significant[16].

To understand the statistical relationship between corruption and R&D investments further, I run the regression of the following form:

$$Y_{jft} = \beta_0 + \beta_1 c_{ft} + \alpha_j + \psi_{st} + \varepsilon_{jft} \tag{2.7}$$

where Y_{jft} is the firm j's R&D investment level, $c_{ft} \in \{0, 1\}$ is the corruption variable defined above, and α_j denotes the firm fixed effects. ψ_{st} is an industry-time fixed effect, where (manufacturing) industries are classified using 2-digit SIC codes. The standard errors are clustered on country of origin, industry and time levels. The estimation results can be found in the first column of Table 2.2 in Appendix CE: β_1 is estimated to be positive and statistically significant.

It may be the case that these results are driven by the firm size effect - larger firms invest in R&D more, and they may be predominantly located in non-corrupt states. In order to control for this possibility, I estimate the same regression equation and control for the number of employees in each firm. Column 2 in Table 2.2 in Appendix CE reports the results: β_1 is still positive and statistically significant.

15. In the whole sample (exporters and non-exporters), 64.6% of the firms are manufacturing firms.

16. For the pooled sample of both manufacturing and non-manufacturing firms, I find that the firms from non-corrupt countries on average invest around 5 times more into R&D than the ones from corrupt countries, and the difference in averages is statistically significant.

Given that around 20% of R&D investments in the data are carried out by the US firms, and the US is classified as "not corrupt" in every single sample year, the results of the above regression could be impacted by the presence of the US firms in the sample. Hence, as a robustness check, I estimate the model in (2.7) by excluding the US firms from the sample. The results still hold, which means β_1 is positive and significantly different from zero.

Thus, the empirical results suggest that the firm level R&D investments are negatively associated with the corruption levels in firms' countries of origin: firms from corrupt countries innovate significantly less than firms from non-corrupt ones. This is in line with what the theoretical model presented above predicts.

Several other papers report similar results regarding the relationship between corruption and innovation. For the US, Ellis et al. (2020) finds that an increase in corruption is associated with a 17.4% decline in the number of firm patents. Huang and Yuan (2020) uses the number of corruption convictions of public officials as their measure of corrupt activity and shows that firms located in corrupt areas of the US are less innovative. Xu and Yano (2016) analyzes how anti-corruption measures implemented in Chinese provinces impact firms' R&D investments and finds that firms located in provinces with strong anti-corruption measures invest significantly more into R&D and generate more patents. Anokhin and Schulze (2009) uses panel data from 64 countries and finds a positive correlation between their corruption measure and innovative activity across nations. Using the dataset from 110 countries, Pirtea et al. (2019) also confirms the positive relationship between corruption and firms' innovative activity. Paunov (2016) uses firm-level data from 48 countries and finds that even though corruption doesn't lower patenting, it decreases machinery investments for innovation.

2.4.4 The relationship between export shock and innovation

To estimate the impact of an export shock on firms' R&D levels and analyze how that impact is correlated with the corruption levels in the countries of origin, I estimate the following model:

$$Y_{jft} = \gamma_0 + \gamma_1 E_{jft} + \gamma_2 c_{ft} + \gamma_3 \Big(E_{jft} \times c_{ft} \Big) + \gamma_4 L_{jft} + \mathbf{X}'_{jft} \tilde{\gamma} + \tilde{\varepsilon}_{jft} \tag{2.8}$$

where Y_{jft}, E_{jft} and c_{ft} are as defined above. L_{jft} denotes the number of employees of a firm j, which is included to control for a possible firm size effect discussed above. $\mathbf{X}_{jft}$ is vector that includes fixed effects. I will estimate different specifications of the model, depending on the fixed effects included in $\mathbf{X}_{jft}$.

Recall that the theoretical model predicts the export demand shock should increase the R&D investments of firms from non-corrupt countries more than the ones from corrupt ones if the market size effect dominates for all firms. However, it can also be the case that the competition effect dominates for all firms, and so export demand shock negatively impacts all firms' R&D investments. In that case, the innovation levels of firms from non-corrupt countries should decline less than the ones from corrupt ones. Moreover, according to the model results, it is also possible for R&D investments of firms from corrupt countries to decline or stay the same and the investments of firms from non-corrupt ones to go up, but not vice-versa.

Thus, given the model in (2.8), testing the theoretical predictions is equivalent to testing whether γ_3 is significantly greater than zero. To test that, I run several specifications of the model. In all specifications, the standard errors are clustered on country of origin, 2-digit SIC, and time levels. In the first specification, I do not include any fixed effects and so estimate a plain OLS model. The results can be found in the first column of Table 2.3 in Appendix CE, and they suggest that both γ_1 and γ_3 are significantly greater than zero.

In the second specification, I include dummies for 2-digit SIC codes, interacted with time-fixed effects. The second column of Table 2.3 displays the results of this specification. In the case of the second specification, γ_1 is no longer statistically significant, but γ_3 is positive and significant.

It could be the case that the unobserved time-variant industry-level shocks are specific to countries of origin. To control for that, in the third specification, I include dummies for 2-digit SIC codes, interacted with country of origin and time-fixed effects. The results in column 3 of Table 2.3 suggest that γ_1 has now changed its sign and become negative, but it is not statistically significant. However, in line with the model predictions, γ_3 remains positive and significant.

The Worldscope Geographical Segments dataset allows me to observe firms' primary export destinations. Hence, to control for industry-specific shocks in export destination countries, in the fourth specification, I include the dummy variable for 2-digit SIC codes, interacted with the export destination country and time-fixed effects. In the fifth specification, I add the origin country-industry-time fixed effects to the fourth specification. Columns 4 and 5 of Table 2.3 report the results of the fourth and fifth specifications correspondingly. In both of these specifications, γ_3 remains positive and significant.

Finally, in the sixth specification, I add the firm fixed effects to all the fixed effects in specification 5. The 6^{th} column of Table 2.3 reports the results. Even though γ_3 still remains positive, it is no longer significant once the firm-specific fixed effects are included in the model.

Thus, the empirical results suggest that there is a positive correlation between the impact of export demand shocks on firms' R&D investments and corruption levels in firms' countries of origin, which confirms the predictions of theoretical model[17].

Even though there are several research papers that analyze the impact of exports on innovation[18], to my knowledge, only Paunov (2016) considers a possible relationship between exports, corruption and innovation. However, that paper does not analyze the impact of an export shock on innovative activity. It rather tries to understand whether the impact of corruption on innovation differs among firms, depending on whether they are exporters.

17. As in the previous section, the results are robust to excluding the US firms from the sample.
18. Bleaney and Wakelin (2002), Cai et al. (2020), Clerides et al. (1998), Lileeva and Trefler (2010).

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Appendix for Chapter 2

Appendix CT

Lemma C1

Let each consumer's inverse demand function be given by $p_X = \frac{\alpha - X}{\beta}$ and suppose there are $L > 1$ such consumers. Further, assume that there are N firms supplying the product X. Each firm has a distinct marginal cost, denoted by $c_j^{f(j)}$. Firms engage in Cournot competition and maximize profits, given by:

$$\max_{x_j^{f(j)}} \left\{ L x_j^{f(j)} \left(\frac{\alpha - \left(\sum_{j' \neq j}^{N-1} x_{j'}^{f(j')} \right) - x_j^{f(j)}}{\beta} \right) - c_j^{f(j)} x_j^{f(j)} L \right\}$$

The (asymmetric) Cournot-Nash equilibrium solution for firm j is given by:

$$x_j^{f(j)} = \frac{\alpha + \beta \sum_j^N c_j^{f(j)}}{N+1} - \beta c_j^{f(j)}$$

and the equilibrium profits of firm j are given by:

$$\pi_j^{f(j)} = L \left[\frac{\left(\alpha + \beta \sum_j^N c_j^{f(j)} - \beta (N+1) c_j^{f(j)} \right)^2}{\beta (N+1)^2} \right]$$

Proof

Taking the first order condition of the profit function of some firm j yields to:

$$\frac{\alpha - \left(\sum_{j' \neq j}^{N-1} x_{j'}^{f(j')}\right) - 2x_j^{f(j)}}{\beta} = c_j^{f(j)}$$

For every firm $j = \{1, 2, \cdots, N\}$ from $\{f(1), f(2), \cdots, f(N)\}$ we have that:

$$\begin{aligned}
2x_1^{f(1)} + x_2^{f(2)} + x_3^{f(3)} + \cdots + x_N^{f(N)} &= \alpha - \beta c_1^{f(1)} \\
x_1^{f(1)} + 2x_2^{f(2)} + x_3^{f(3)} + \cdots + x_N^{f(N)} &= \alpha - \beta c_2^{f(2)} \\
x_1^{f(1)} + x_2^{f(2)} + 2x_3^{f(3)} + \cdots + x_N^{f(N)} &= \alpha - \beta c_3^{f(3)} \\
&\vdots \\
x_1^{f(1)} + x_2^{f(2)} + x_3^{f(3)} + \cdots + 2x_N^{f(N)} &= \alpha - \beta c_N^{f(N)}
\end{aligned}$$

To write the above system in matrix form, define the following matrices:

$$A = \begin{bmatrix} 2 & 1 & 1 & \dots & 1 \\ 1 & 2 & 1 & \dots & 1 \\ \vdots & & \ddots & & \\ 1 & 1 & 1 & \dots & 2 \end{bmatrix} \quad \overline{X} = \begin{bmatrix} x_1^{f(1)} \\ x_2^{f(2)} \\ \vdots \\ x_N^{f(N)} \end{bmatrix} \quad C = \begin{bmatrix} \alpha - \beta c_1^{f(1)} \\ \alpha - \beta c_2^{f(2)} \\ \vdots \\ \alpha - \beta c_N^{f(N)} \end{bmatrix}$$

Given the definitions, the system can be expressed as:

$$A\overline{X} = C$$

which implies that the solution for $\overline{X}$ is:

$$\overline{X} = A^{-1}C$$

Solving the above system yields the following:

$$\overline{X} = \begin{bmatrix} \frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{N+1} - \beta c_1^{f(1)} \\ \frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{N+1} - \beta c_2^{f(2)} \\ \vdots \\ \frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{N+1} - \beta c_N^{f(N)} \end{bmatrix}$$

Thus, the solution for a firm j is:

$$x_j^{f(j)} = \frac{\alpha + \beta \sum_j^N c_j^{f(j)}}{N+1} - \beta c_j^{f(j)}$$

Thus, the total amount supplied to each individual i is:

$$\begin{aligned} X = \sum_j^N x_j^{f(j)} &= \sum_j^N \Big(\frac{\alpha + \beta \sum_j^N c_j^{f(j)}}{N+1} - \beta c_j^{f(j)} \Big) \\ &= \frac{N\alpha - \beta \sum_j^N c_j^{f(j)}}{N+1} \end{aligned}$$

and the price of the export product is:

$$\begin{aligned} p_x = \frac{\alpha - X}{\beta} &= \frac{\alpha - \left(\frac{N\alpha - \beta\sum_j^N c_j^{f(j)}}{N+1} \right)}{\beta} \\ &= \frac{\alpha + \beta \sum_j^N c_j^{f(j)}}{\beta(N+1)} \end{aligned}$$

Finally, a firm j's equilibrium profit function is:

$$
\begin{aligned}
\pi_j^{f(j)} =& L\Bigg[\Bigg(\frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{N+1} - \beta c_j^{f(j)}\Bigg)\Bigg(\frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{\beta(N+1)}\Bigg) - c_j^{f(j)}\Bigg(\frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{N+1} - \beta c_j^{f(j)}\Bigg)\Bigg] \\
=& L\Bigg[\Bigg(\frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{N+1} - \beta c_j^{f(j)}\Bigg)\Bigg(\frac{\alpha+\beta\sum_j^N c_j^{f(j)}}{\beta(N+1)} - c_j^{f(j)}\Bigg)\Bigg] \\
=& L\Bigg[\frac{\Big(\alpha+\beta\sum_j^N c_j^{f(j)} - \beta(N+1)c_j^{f(j)}\Big)^2}{\beta(N+1)^2}\Bigg]
\end{aligned}
$$

Lemma C2

Suppose firms choose their R&D investments simultaneously to maximize their profits. That is, a firm j takes $\sum_{j'\neq j}^{N-1} c_{j'}^{f(j')}$ as given and chooses $\varepsilon_j^{f(j)}$ to maximize the following expression:

$$
\max_{\varepsilon_j^{f(j)}}\Bigg\{L\Bigg[\frac{\Big(\alpha+\beta\sum_{j'\neq j}^{N-1} c_{j'}^{f(j')} - \beta N\big(\tilde{c}_j^{f(j)} - \varepsilon_j^{f(j)}\big)\Big)^2}{\beta(N+1)^2}\Bigg] - \frac{\big(\varepsilon_j^{f(j)}\big)^2}{2} - B^{f(j)}\Bigg\}
$$

Then, the first order condition for $\varepsilon_j^{f(j)}$ yields to the following equilibrium condition:

$$
\varepsilon_j^{f(j)}\frac{1}{2}\Bigg(\frac{\big(N+1\big)^2}{N}\Bigg) - L\beta c_e\Big(\sum_{j'\neq j}^{N-1}\big(\gamma^{f(j')}-\gamma^{f(j)}\big)\Big)\Bigg(\frac{N+1}{N+1-2\beta LN}\Bigg) = L\Big(\alpha-\beta c_e\gamma^{f(j)}\Big) + L\beta\varepsilon_j^{f(j)}
$$

which implies that the expression for the profit-maximizing value of $\varepsilon_j^{f(j)}$ is given by:

$$
\varepsilon_j^{f(j)} = \frac{2LN\Big(\alpha-\beta c_e\gamma^{f(j)}\Big) + L\beta c_e\Big(\sum_{j'\neq j}^{N-1}\big(\gamma^{f(j')}-\gamma^{f(j)}\big)\Big)\Bigg(\frac{N+1}{N+1-2\beta LN}\Bigg)}{\Big(\big(N+1\big)^2 - 2LN\beta\Big)}
$$

Proof

Taking the first order condition yields to:

$$\frac{2L}{\beta(N+1)^2}\Big(\alpha+\beta\sum_{j'\neq j}^{N-1}c_{j'}^{f(j')}-\beta N\big(\tilde{c}_j^{f(j)}-\varepsilon_j^{f(j)}\big)\Big)\beta N-\varepsilon_j^{f(j)}=0$$

Rearranging this expression yields to:

$$\begin{aligned}\frac{2LN}{(N+1)^2}\Big(\alpha+\beta\sum_{j'\neq j}^{N-1}c_{j'}^{f(j')}-\beta N\tilde{c}_j^{f(j)}\Big)+\frac{2\beta LN^2}{(N+1)^2}\varepsilon_j^{f(j)}&=\varepsilon_j^{f(j)}\\ 2LN\Big(\alpha-\beta N\tilde{c}_j^{f(j)}\Big)+2LN\beta\sum_{j'\neq j}^{N-1}c_{j'}^{f(j')}+2\beta N^2L\varepsilon_j^{f(j)}&=\varepsilon_j^{f(j)}(N+1)^2\\ \varepsilon_j^{f(j)}\Big((N+1)^2-2\beta N^2L\Big)-2LN\beta\sum_{j'\neq j}^{N-1}c_{j'}^{f(j')}&=2LN\Big(\alpha-\beta N\tilde{c}_j^{f(j)}\Big)\end{aligned}$$

Using the definition of $c_{j'}^{f(j')}=\tilde{c}_{j'}^{f(j')}-\varepsilon_{j'}^{f(j')}$, the above expression can be written as:

$$\begin{aligned}\varepsilon_j^{f(j)}\Big((N+1)^2-2\beta N^2L\Big)-2LN\beta\Big(\sum_{j'\neq j}^{N-1}\tilde{c}_{j'}^{f(j')}-\sum_{j'\neq j}^{N-1}\varepsilon_{j'}^{f(j')}\Big)&=2LN\Big(\alpha-\beta N\tilde{c}_j^{f(j)}\Big)\\ \varepsilon_j^{f(j)}\Big((N+1)^2-2\beta N^2L\Big)+2LN\beta\sum_{j'\neq j}^{N-1}\varepsilon_{j'}^{f(j')}&=2LN\Big(\alpha-\beta N\tilde{c}_j^{f(j)}+\beta\sum_{j'\neq j}^{N-1}\tilde{c}_{j'}^{f(j')}\Big)\end{aligned}$$

Note that $\sum_{j'\neq j}^{N-1}\tilde{c}_{j'}^{f(j')}=\sum_{j'}^{N}\tilde{c}_{j'}^{f(j')}-\tilde{c}_j^{f(j)}$. Define $\sum_{j'}^{N}\tilde{c}_{j'}^{f(j')}\equiv\tilde{\mathbf{C}}$ as the total baseline cost of all exporters and substitute it into the above expression:

$$\varepsilon_j^{f(j)}\Big((N+1)^2-2\beta N^2L\Big)+2LN\beta\sum_{j'\neq j}^{N-1}\varepsilon_{j'}^{f(j')}=2LN\Big(\alpha-\beta N\tilde{c}_j^{f(j)}+\beta\big(\tilde{\mathbf{C}}-\tilde{c}_j^{f(j)}\big)\Big)$$

For the clarity of the solution, I introduce the following notations. Let $x \equiv \Big((N+1)^2 - 2\beta N^2 L\Big)$, $q \equiv 2LN\beta$ and $\phi_j \equiv 2LN\Big(\alpha - \beta N \tilde{c}_j^{f(j)} + \beta\big(\tilde{\mathbf{C}} - \tilde{c}_j^{f(j)}\big)\Big)$. The above expression becomes:

$$x\varepsilon_j^{f(j)} + q\sum_{j'\neq j}^{N-1} \varepsilon_{j'}^{f(j')} = \phi_j^{f(j)}$$

This implies that the system of best response functions are:

$$\begin{aligned}
x\varepsilon_1^{f(1)} + q\varepsilon_2^{f(2)} + q\varepsilon_3^{f(3)} + \cdots + q\varepsilon_N^{f(N)} &= \phi_1^{f(1)} \\
q\varepsilon_1^{f(1)} + x\varepsilon_2^{f(2)} + q\varepsilon_3^{f(3)} + \cdots + q\varepsilon_N^{f(N)} &= \phi_2^{f(2)} \\
q\varepsilon_1^{f(1)} + q\varepsilon_2^{f(2)} + x\varepsilon_3^{f(3)} + \cdots + q\varepsilon_N^{f(N)} &= \phi_3^{f(3)} \\
&\vdots \\
q\varepsilon_1^{f(1)} + q\varepsilon_2^{f(2)} + q\varepsilon_3^{f(3)} + \cdots + x\varepsilon_N^{f(N)} &= \phi_N^{f(N)}
\end{aligned}$$

To write the above system in matrix form, define the following matrices

$$B = \begin{bmatrix} x & q & q & \dots & q \\ q & x & q & \dots & q \\ \vdots & & \ddots & & \\ q & q & q & \dots & x \end{bmatrix} \qquad \overline{\varepsilon} = \begin{bmatrix} \varepsilon_1^{f(1)} \\ \varepsilon_2^{f(2)} \\ \vdots \\ \varepsilon_N^{f(N)} \end{bmatrix} \qquad \overline{\phi} = \begin{bmatrix} \phi_1^{f(1)} \\ \phi_2^{f(2)} \\ \vdots \\ \phi_N^{f(N)} \end{bmatrix}$$

The solution for $\overline{\varepsilon}$ can be found as:

$$\overline{\varepsilon} = B^{-1}\overline{\phi}$$

The inverse of B can be shown to be of the following form:

$$B^{-1} = \frac{1}{x^2 + (N-2)qx - (N-1)q^2} \begin{bmatrix} (N-2)q + x & -q & -q & \dots & -q \\ -q & (N-2)q + x & -q & \dots & -q \\ \vdots & & \ddots & & \\ -q & -q & -q & \dots & (N-2)q + x \end{bmatrix}$$

Thus, the equilibrium solution for $\varepsilon_j^{f(j)}$ is given by:

$$\varepsilon_j^{f(j)} = \frac{1}{x^2 + (N-2)qx - (N-1)q^2}\Big(\big((N-2)q + x\big)\phi_j - q\sum_{j' \neq j}^{N-1} \phi_{j'}\Big) \tag{2.9}$$

I will now proceed to simplifying this expression to derive the result of the lemma. I will first simplify the numerator. Consider $\big((N-2)q + x\big)\phi_j$:

$$\big((N-2)q + x\big)\phi_j = \big((N-2)q + x\big)\left(2LN\Big(\alpha - \beta N\tilde{c}_j^{f(j)} + \beta\big(\tilde{\mathbf{C}} - \tilde{c}_j^{f(j)}\big)\Big)\right)$$

Combining the common terms yields to:

$$\big((N-2)q + x\big)\phi_j = \big((N-2)q + x\big)2LN\left(\alpha + \beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\right) \tag{2.10}$$

The expression $q\sum_{j' \neq j}^{N-1} \phi_{j'}$ can be simplified as follows:

$$\begin{aligned} q\sum_{j' \neq j}^{N-1} \phi_{j'} = & q\left(\sum_{j' \neq j}^{N-1}\Big(2LN\Big(\alpha - \beta N\tilde{c}_{j'}^{f(j')} + \beta\big(\tilde{\mathbf{C}} - \tilde{c}_{j'}^{f(j')}\big)\Big)\Big)\right) \\ =& 2qLN\left(\alpha(N-1) - \beta N\sum_{j' \neq j}^{N-1}\tilde{c}_{j'}^{f(j')} + \beta(N-1)\tilde{\mathbf{C}} - \beta\sum_{j' \neq j}^{N-1}\tilde{c}_{j'}^{f(j')}\right) \\ =& 2qLN\left(\alpha(N-1) - \beta N\big(\tilde{\mathbf{C}} - \tilde{c}_{j'}^{f(j')}\big) + \beta(N-1)\tilde{\mathbf{C}} - \beta\big(\tilde{\mathbf{C}} - \tilde{c}_{j'}^{f(j')}\big)\right) \end{aligned}$$

which implies that:

$$q\sum_{j'\neq j}^{N-1}\phi_{j'} = 2qLN\Bigg(\alpha(N-1) - 2\beta\tilde{\mathbf{C}} + \beta\tilde{c}_{j'}^{f(j')}\big(N+1\big)\Bigg) \tag{2.11}$$

By combining (2.10) and (2.11), next, I will obtain the expression for the whole numerator:

$$\begin{aligned}
\big((N-2)q+x\big)\phi_j - q\sum_{j'\neq j}^{N-1}\phi_{j'} &= \Big(\big(N-2\big)q+x\Big)2LN\Bigg(\alpha + \beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\Bigg)\\
&- 2qLN\Bigg(\alpha(N-1) - 2\beta\tilde{\mathbf{C}} + \beta\tilde{c}_{j'}^{f(j')}\big(N+1\big)\Bigg)\\
&= 2qLN\Bigg(\alpha\big(N-2\big) + \beta\tilde{\mathbf{C}}\big(N-2\big) - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\big(N-2\big)\Bigg)\\
&+ 2LNx\Bigg(\alpha + \beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\Bigg)\\
&- 2qLN\Bigg(\alpha(N-1) - 2\beta\tilde{\mathbf{C}} + \beta\tilde{c}_{j'}^{f(j')}\big(N+1\big)\Bigg)\\
&= 2qLN\Bigg(\alpha\big(N-2-N+1\big) + \beta\tilde{\mathbf{C}}\big(N-2+2\big) - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\big(N-2+1\big)\Bigg)\\
&+ 2LNx\Bigg(\alpha + \beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\Bigg)\\
&= 2qLN\Bigg(-\alpha + N\beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\big(N-1\big)\Bigg)\\
&+ 2LNx\Bigg(\alpha + \beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\Bigg)\\
&= 2qLN\Bigg(-\alpha + \big(N+1\big)\beta\tilde{\mathbf{C}} - \tilde{\mathbf{C}}\beta - N\beta\tilde{c}_j^{f(j)}\big(N+1\big) + \beta\tilde{c}_j^{f(j)}\big(N+1\big)\Bigg)\\
&+ 2LNx\Bigg(\alpha + \beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\Bigg)\\
&= 2LN\Big(x-q\Big)\Bigg(\alpha + \beta\tilde{\mathbf{C}} - \beta\tilde{c}_j^{f(j)}\big(N+1\big)\Bigg) + 2qLN\big(N+1\big)\beta\Big(\tilde{\mathbf{C}} - N\tilde{c}_j^{f(j)}\Big)\\
&= 2LN\Big(x-q\Big)\Big(\alpha - \beta\tilde{c}_j^{f(j)}\Big) + 2LN\beta\Big(\tilde{\mathbf{C}} - N\tilde{c}_j^{f(j)}\Big)\Big(x-q+q\big(N+1\big)\Big)
\end{aligned}$$

Which implies that:

$$\big((N-2)q+x\big)\phi_j - q\sum_{j'\neq j}^{N-1}\phi_{j'} = 2LN\Big(x-q\Big)\Big(\alpha-\beta\tilde{c}_j^{f(j)}\Big) + 2LN\beta\Big(\tilde{\mathbf{C}}-N\tilde{c}_j^{f(j)}\Big)\Big(x+qN\Big) \quad (2.12)$$

Now, consider the denominator:

$$\begin{aligned} x^2+(N-2)qx-(N-1)q^2 &= x^2+Nqx-2qx-Nq^2+q^2 \\ &= (x-q)^2+Nq(x-q) \\ &= (x-q)(x+q(N-1)) \end{aligned}$$

Combining this expression for the denominator with the expression for the numerator from (2.12), the expression for $\varepsilon_j^{f(j)}$ from (2.9) can be written as:

$$\Big(x-q\Big)\Big(x+q\big(N-1\big)\Big)\varepsilon_j^{f(j)} = 2LN\Big(x-q\Big)\Big(\alpha-\beta\tilde{c}_j^{f(j)}\Big) + 2LN\beta\Big(\tilde{\mathbf{C}}-N\tilde{c}_j^{f(j)}\Big)\Big(x+qN\Big)$$

$$\big(x+q(N-1)\big)\varepsilon_j^{f(j)} = 2LN\Big(\alpha-\beta\tilde{c}_j^{f(j)}\Big) + 2LN\beta\Big(\tilde{\mathbf{C}}-N\tilde{c}_j^{f(j)}\Big)\left(\frac{x+qN}{x-q}\right) \quad (2.13)$$

The next step is to substitute in the definitions of x and q:

$$\begin{aligned} x-q =& \big(N+1\big)^2 - 2\beta N^2L - 2LN\beta \\ =& \big(N+1\big)^2 - 2\beta LN\big(N+1\big) \\ =& \big(N+1\big)\big(N+1-2\beta LN\big) \end{aligned}$$

$$x+qN = \big(N+1\big)^2 - 2\beta N^2L + 2LN^2\beta = \big(N+1\big)^2$$

Therefore, I have that:

$$\frac{x+qN}{x-q} = \frac{\big(N+1\big)^2}{\big(N+1\big)\big(N+1-2\beta LN\big)} = \frac{N+1}{N+1-2\beta LN}$$

Finally, for the left-hand side of (2.13):

$$x + q(N-1) = \big(N+1\big)^2 - 2\beta N^2 L + 2LN^2\beta - 2LN\beta = \big(N+1\big)^2 - 2LN\beta$$

Substituting the solutions for the expression with x and q into (2.13) implies:

$$\Big(\big(N+1\big)^2 - 2LN\beta\Big)\varepsilon_j^{f(j)} = 2LN\Big(\alpha - \beta\tilde{c}_j^{f(j)}\Big) + 2LN\beta\Big(\tilde{\mathbf{C}} - N\tilde{c}_j^{f(j)}\Big)\left(\frac{N+1}{N+1-2\beta LN}\right)$$

Finally, note that:

$$\tilde{\mathbf{C}} - N\tilde{c}_j^{f(j)} = \sum_{j'\neq j}^{N-1}\big(\tilde{c}_{j'}^{f(j')} - \tilde{c}_j^{f(j)}\big)$$

which is the sum of the differences between the baseline cost levels of all firms and the one of firm j. Using this result implies that the equilibrium value of $\varepsilon_j^{f(j)}$ is:

$$\varepsilon_j^{f(j)} = \frac{2LN\Big(\alpha - \beta\tilde{c}_j^{f(j)}\Big) + 2LN\beta\Big(\sum_{j'\neq j}^{N-1}\big(\tilde{c}_{j'}^{f(j')} - \tilde{c}_j^{f(j)}\big)\Big)\left(\frac{N+1}{N+1-2\beta LN}\right)}{\Big(\big(N+1\big)^2 - 2LN\beta\Big)} \tag{2.14}$$

To prove the first result of the lemma, rearrange the expression further:

$$\varepsilon_j^{f(j)}\frac{1}{2}\left(\frac{\big(N+1\big)^2}{N}\right) - L\beta\varepsilon_j^{f(j)} = L\Big(\alpha - \beta\tilde{c}_j^{f(j)}\Big) + L\beta\Big(\sum_{j'\neq j}^{N-1}\big(\tilde{c}_{j'}^{f(j')} - \tilde{c}_j^{f(j)}\big)\Big)\left(\frac{N+1}{N+1-2\beta LN}\right)$$

$$\varepsilon_j^{f(j)}\frac{1}{2}\left(\frac{\big(N+1\big)^2}{N}\right) - L\beta\Big(\sum_{j'\neq j}^{N-1}\big(\tilde{c}_{j'}^{f(j')} - \tilde{c}_j^{f(j)}\big)\Big)\left(\frac{N+1}{N+1-2\beta LN}\right) = L\Big(\alpha - \beta\tilde{c}_j^{f(j)}\Big) + L\beta\varepsilon_j^{f(j)}$$

Replacing $\tilde{c}_j^{f(j)}$ with $\tilde{c}_j^{f(j)} = c_e\gamma^{f(j)}$ in the above expressions completes the proof.

Appendix CE

	Freq.	Percent
Australia	11157	3.149
Belgium	207	0.0584
Brazil	731	0.206
Canada	18009	5.083
China	41645	11.75
Denmark	583	0.165
Finland	1884	0.532
France	5093	1.437
Germany	7082	1.999
Greece	1009	0.285
Hong Kong	5823	1.644
India	14325	4.043
Ireland	1024	0.289
Israel	4257	1.202
Italy	943	0.266
Japan	51104	14.42
South Korea	27961	7.892
Malaysia	2485	0.701
Netherlands	1491	0.421
New Zealand	524	0.148
Norway	636	0.180
Russian Federation	1058	0.299
Singapore	1557	0.439
South Africa	1236	0.349
Sweden	3324	0.938
Switzerland	2936	0.829

Taiwan	28179	7.953
Thailand	398	0.112
Turkey	2876	0.812
United Kingdom	13975	3.944
United States	100792	28.45
Total	354304	100

Table 2.1: Distribution of firms across countries in Worldscope dataset.

	(1)	(2)
	Y_{jft}	Y_{jft}
c_{ft}	15090008.2*	4452236.7**
	(5357667.2)	(1298114.8)
$Labor_{jft}$		15837.1***
		(2519.2)
_cons	148774153.5***	51910376.1*
	(3638882.9)	(19322271.1)

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.2: Regression results from the fixed effects regression of R&D on corruption. Standard errors are clustered on country, 2-digit SIC code and time levels. Both regressions include firm and industry-time fixed effects.

	(1)	(2)	(3)	(4)	(5)	(6)
	Y_{jft}	Y_{jft}	Y_{jft}	Y_{jft}	Y_{jft}	Y_{jft}
γ_1	8397.4*	3140.5	-9.706	3512.8	-3422.5	701887.5
	(3262.1)	(4687.7)	(3452.6)	(7625.7)	(5021.0)	(483644.8)
γ_3	30652.0***	35549.6***	38994.3**	56743.4**	57961.7**	42561.4
	(6082.6)	(8721.6)	(10180.6)	(18206.4)	(18020.1)	(54046.3)
γ_2	72748461.7*	72311205.1	-	18413044.3	-	-
	(29199394.2)	(42568572.4)	(-)	(102690849.0)	(-)	(-)
γ_4	19873.5***	20668.1***	23403.0***	22481.5***	24947.5***	17741.5***
	(4887.1)	(4672.2)	(4666.6)	(4312.9)	(4329.6)	(1818.9)
γ_0	-109999509.5**	-114410727.1**	-84361255.5	-113226948.1	-113542098.7	-1.55822e+09
	(31900144.9)	(39574212.7)	(66666755.6)	(55671251.9)	(82906382.0)	(1.17145e+09)
Fixed effects:						
SIC×Year	No	Yes	No	No	No	No
Origin×SIC×Year	No	No	Yes	No	Yes	Yes
Destination×SIC×Year	No	No	No	Yes	Yes	Yes
Firm	No	No	No	No	No	Yes

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.3: Regression results from the fixed effects regressions of R&D on corruption and export demand shock.

Figure 2.3: Correlation between % of R&D in GDP and Total Exports

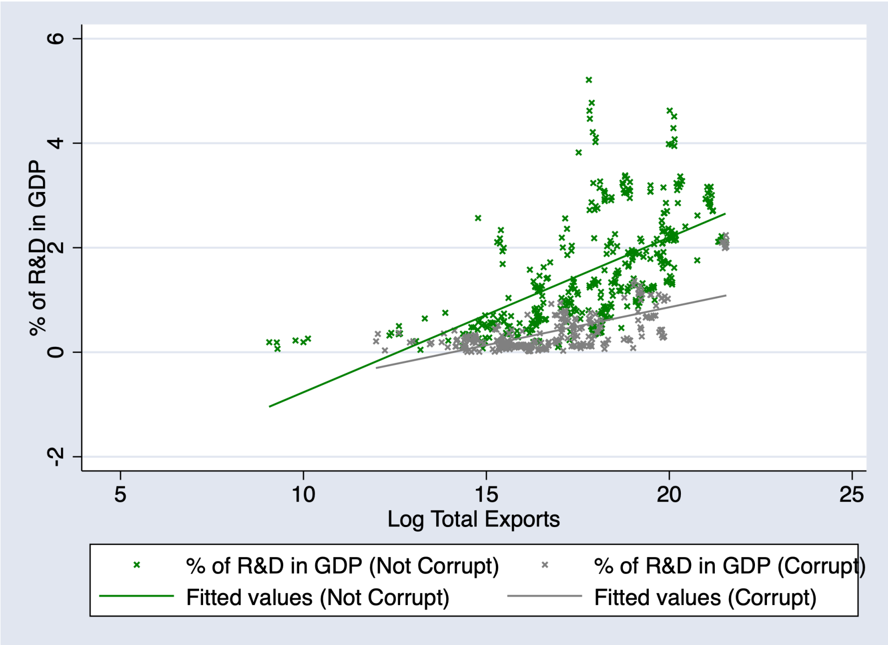
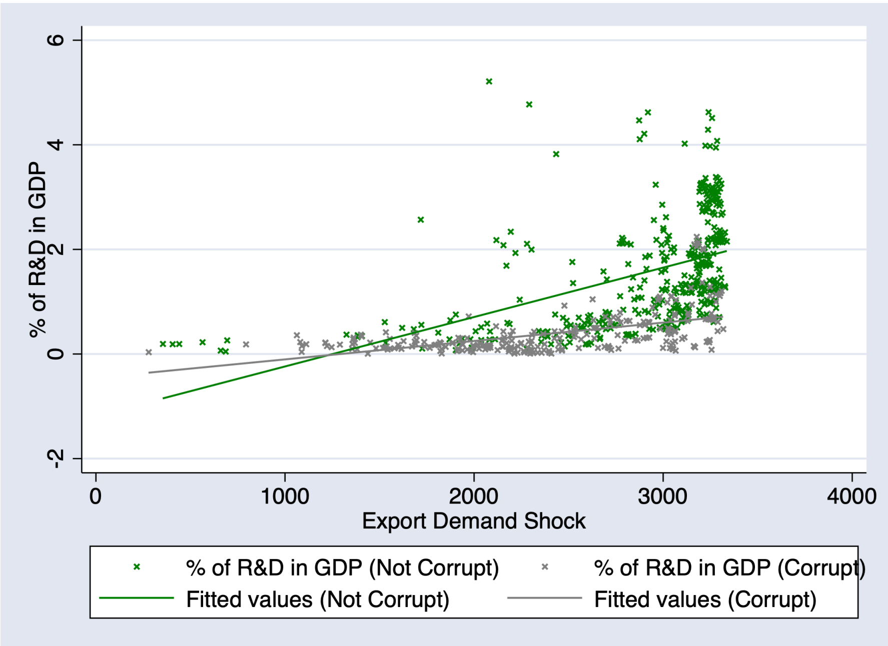


Figure 2.4: Correlation between % of R&D in GDP and Exogenous Export Demand Shock



Chapter 3

Vertical Industrial Relations, Market Competition and Innovation Incentives

3.1 Introduction

It is broadly agreed among economists that R&D is an engine of economic growth (Aghion and Howitt (1998), Aghion and Howitt (2009), Acemoglu (2009)). Therefore, the question of what influences R&D investments and how has been one of the main focuses of the Growth and IO literature. In particular, although without a definite conclusion, economists in various fields have been trying to understand for decades whether market competition *among innovating firms* is detrimental to innovation or encouraging it. This question has received so much attention that it has even been called the "second-most tested hypothesis in industrial organization" (Aghion and Tirole (1994)).

In this paper, I take a slightly different approach and note that there are industries that are not innovating themselves but are using the products of innovations. More precisely, the innovating firms (upstream) may be supplying the products of their innovation to other sectors (downstream), in which firms are not innovating themselves but are using the products of upstream innovations to carry out their business. Many examples of such relations can be given, such as technology producers supplying their products to non-technology producing firms (e.g. PC companies supplying their products to non-tech businesses).

Following the structure of vertical relations described above, this paper asks the following question: "Given that there are innovating and non-innovating industries, how does the competition in *both* of such industry types affect the innovation process?". To my knowledge, this paper is the first one that attempts to address such a question, and it is the first one that presents results regarding how competition in non-innovating downstream industries may affect the innovation incentives of upstream innovators.

In order to address this question, I develop an endogenous growth model in the spirit of Aghion and Howitt (1992), Grossman and Helpman (1991), and Aghion et al. (2005). I present two versions of the model: a more basic version of the model in discrete time and a continuous time version. The results and basic features of the two models are the same, although solving the continuous time version imposed several difficulties, which I describe in Section 3.5. The economy in the models consists of four main parts: (i) Technology producers (innovators); (ii) Intermediate good producers, which use products of innovators and do not innovate themselves; (iii) Final good producers, which use intermediate goods to produce the final good and (iv) Consumers, who consume and supply labour. As in Aghion et al. (2005), I assume that technology-producing industries can be of two types: duopolistic sectors, in which the firms are on the same technological level and monopolistic sectors, in which an incumbent monopolist faces a potential entrant. If one of the duopolists innovates successfully, that firm moves one technological step ahead and becomes a monopolist. In addition, the structure of the model is such that, in order to enter the market, a potential entrant into a monopolistic sector must innovate and first reach the technological level of an incumbent monopolist, in which case the sector turns into a duopoly (i.e. an entrant cannot "leapfrog" and derive an incumbent out of the market immediately). Similarly, I assume that at any given point in time, an intermediate good sector can also be occupied either by a monopolist or by two oligopolists. In monopolistic intermediate goods sectors, an incumbent faces a potential entrant. Incentives of an entrant to enter the market are influenced by post-entry competition levels, such that higher post-entry competition in an intermediate good industry discourages an entrant from entering. Likewise, in duopolistic downstream sectors, there is a chance that one of the firms quits the industry, and the incentives of one of the duopolists to stay in the market decline with higher levels of competition in that intermediate goods sector. The final good sector is assumed to be competitive.

Regarding the effect of competition among *innovating* firms on their innovation incentives, I show that in oligopolistic technology-producing sectors, higher levels of competition increase incentives of duopolists to innovate. However, in monopolistic technology-producing sectors, higher (post-entry) competition decreases the incentives for an entrant to innovate and enter into a market. A similar finding was also reported in Aghion et al. (2005). The intuition behind this result is that higher competition levels among oligopolists encourage firms to innovate, as the innovating firm moves one technological step ahead and becomes a monopolist. However, in monopolistic sectors, higher competition levels discourage an entrant from innovating, as post-entry profits are low as a result of tougher (post-entry) competition.

The relation between competition in *non-innovating* industries and innovation incentives of upstream technology producers is shown to be either U-shaped or declining. In order to understand the intuition behind this result, note that what determines the innovation incentives of firms are (expected) post-innovation rents, such that higher expected post-innovation rents encourage firms to innovate more. Furthermore, upstream technology producer(s) would prefer the downstream industries to be occupied by monopolists because, in the case of a duopoly, as the downstream firms compete, the total amount of rents that upstream firm(s) can collect is lower. Given this, consider a technology-producing sector supplying a downstream (intermediate) monopolist sector[1]. There are two effects of increased (post-entry) competition levels in a downstream industry. First, as discussed, in case an entrant downstream enters, higher competition reduces total profits made downstream, and so decreases the rents that upstream firms can capture from the downstream one; this effect reduces the expected post-innovation rents of the upstream innovator(s). Second, increased post-entry competition downstream reduces incentives for an entrant in a downstream

1. The case of the technology-producing sector supplying a downstream (intermediate) duopolist sector is considered in Section 3.4.

sector to enter and so positively affects the expected post-innovation rents of the upstream firm(s). These two counteracting effects are the ones that derive the results. In section 3.4, I show that if the probability of an entrant entering the downstream industry is responsive enough to changes in competition levels, for low levels of intermediate good competition, the first effect dominates, and so innovation incentives decline with higher levels of competition downstream; and for high levels of competition the second effect starts to dominate, which implies a U-shape. However, if the probability of an entrant entering the downstream industry is not responsive enough to changes in competition levels, the first negative effect always dominates the second one, which implies a decreasing relation between competition in non-innovating industries and innovation incentives of upstream technology producers.

I also show that the effect of higher competition levels among innovating firms on the economy's growth rate is positive. The effect of higher competition levels in non-innovating sectors on the growth rate of the economy is shown to be either U-shaped or negative.

The chapter is organized as follows: Section 3.2 provides a review of the literature; Section 3.4 presents the benchmark model in discrete time and a discussion of results; Section 3.5 presents the continuous time version of the model and provides the simulation results; finally, Section 3.6 summarizes and concludes the paper, followed by the appendices and bibliography.

3.2 Literature review

As was mentioned in the introduction section, the literature that explores the relation between innovation and competition is immense. There are many surveys/books on this matter, such as Aghion and Griffith (2005), which can be consulted. I will mention the most relevant papers for the purpose of this work here.

The early endogenous growth literature (Romer (1990), Aghion and Howitt (1992), Grossman and Helpman (1991)) predicted that higher product market competition has a negative effect on innovations and so on economic growth. Although the predictions of these models are the same in terms of the relation of competition and innovation, the causes of these results are different. Aghion and Howitt (1992) and Grossman and Helpman (1991) rely on Schumpeter's "creative destruction" idea that the monopoly rents encourage innovations. However, Romer (1990)'s prediction of negative relation relies on the Dixit and Stiglitz (1977) model of monopolistic competition, which, like many early IO models of competition, product differentiation and entry, predicts that higher competition discourages innovations and entry.

However, not all early theoretical models of IO predict a negative effect of higher market competition on entry and innovation. For instance, as discussed in Tirole (1988), there can be two counteracting effects that determine an incumbent monopolist's innovation incentives: replacement and rent dissipation effects. The replacement effect is Arrow's famous idea that a monopolist has lower incentives to innovate as it replaces its own profits, but an entrant has no profits to replace and so has higher incentives to innovate and enter. However, an incumbent monopolist may lose more by letting an entrant enter, as it loses the difference between monopoly profits and duopoly profits in case an entrant enters. This latter effect is the rent dissipation effect, and if it dominates the replacement effect, then the incumbent ends up innovating more as a result of potential entry.

Due to the availability of rich firm-level datasets, starting from the end of the 1990s, more recent papers that analyze the relation between competition and innovation tend to be empirical[2]. The findings presented in the empirical papers were at odds with the early theoretical predictions, as most of the papers reported a positive relationship between innovation and competition. For instance, Nickell (1996), alongside other findings, reports that increased competition is associated with higher levels and faster growth rate of total factor productivity. Blundell et al. (1999) finds that more competitive industries have higher aggregate innovation levels. Both of the above-mentioned papers use data on UK firms. Similarly, many other empirical works, such as Symeonidis (2002), Baily and Gersbach (1995) and Geroski (1998), report a positive relationship between competition and innovations

Given the emergence of empirical evidence that contradicted early theoretical predictions, sev-

2. Although there are methodological issues with many of the empirical papers, such as issues with measurement of innovations and competition, I am not going to discuss them in this paper, but report the results only.

eral theoretical models of competition and innovation that can incorporate the positive relation were proposed. One of them is Vives (2008), which considers two different measures of market competition: an increase in the number of competitors and an increase in the degree of product substitutability. Vives (2008) shows that increasing the number of competitors decreases R&D investments, but increasing the degree of product substitutability encourages it. In addition to this, another attempt to model a positive relation between competition and entry is Aghion and Schankerman (2004). The authors show that if, on top of being horizontally differentiated, the firms are also vertically differentiated by their costs, increased competition can enhance innovations.

A paper which is very closely related to this one is Aghion et al. (2005). In that paper, the authors provide empirical evidence (from the UK) that the relationship between competition and innovation can have an inverted U shape. In fact, it is the empirical approach of Aghion et al. (2005) that motivated the idea of this paper. In order to measure competition among firms, Aghion et al. (2005) uses "...the entire sample of Stock Market Listed firms in each industry, not only those in the patenting sub-sample.". That is, the paper uses *both* innovating and non-innovating firms to measure competition. Pooling both innovating and non-innovating firms together, however, can produce misleading results for the reasons described in the introduction section: those innovating and non-innovating firms can be interacting in a vertical relationship, and so competition among innovating and non-innovating firms can have different effects on innovation incentives. The authors also provide a theoretical model that attempts to explain the inverted U relationship. The main idea is that competition increases innovation incentives of oligopolists that are on the same technological ladder but discourages entrants into monopolistic sectors from innovating and entering. Aghion et al. (2005) shows that given that the steady-state fraction of monopolists vs oligopolists is an equilibrium object itself, inverted-U is generated by these two counteracting effects of competition on innovation incentives. Aghion et al. (2018) provides some evidence from a laboratory experiment that supports this explanation.

Finally, there are a few papers that attempt to analyze the innovation process within the context of vertical industrial relations. One of them is Acemoglu et al. (2010). In that paper, both upstream and downstream firms innovate, and the paper analyzes how vertical integration affects the technology intensities of upstream and downstream firms. It finds that the technology intensities of upstream firms increase with the probability of being integrated, but the intensities of downstream firms decline with a higher likelihood of integration. More closely linked to this current paper is the one written by Bourles and co-authors in 2013. However, differently from this paper, Bourles et al. (2013) analyzes how competition in the upstream sector affects the multi-factor productivity growth downstream. That is, in their setup, the downstream sector is the one which invests in R&D. Using the panel data from the OECD countries for the period of 1984-2007, the paper finds that lower competition levels upstream decrease the multi-factor productivity growth in downstream sectors. In addition, Cette et al. (2017) uses the same data as the previous paper and shows that a higher level of anti-competitive regulation upstream (which is the non-innovating sector in their setup) can significantly decrease R&D investments downstream.

3.3 Structure of the economy and timeline of events

The models described in the chapter will be based on the structure of the vertical relationship that can be represented as follows:

Technology Producers (Upstream/Innovating Sectors)

$\downarrow$

Intermediate Good Producers (Downstream/Non-Innovating Sectors)

$\downarrow$

Final Good Producers

$\downarrow$

Consumers

Consumers supply labour and consume some of the final good. The final good sector uses a continuum of intermediate goods for production. Intermediate good producers use the technology supplied by the upstream technology producers in the production of an intermediate good. Innovations in this economy happen only in the technology producers' sectors. The final good sector is competitive. At any given time, a given intermediate good and technology producers' sector can either be occupied by a monopolist or by two oligopolists. The models below will describe in more detail the role of innovations and the market structure in each sector.

In every period t, the timeline of events is as follows[3]:

1. Technology producers make innovation decisions (i.e. with what intensity to innovate)

2. After observing the innovation decision(s) taken by the upstream firm(s), if an intermediate good sector is a monopoly, a potential entrant into that intermediate good sector decides whether to enter or not. Likewise, if an intermediate good sector is occupied by oligopolists, one of the firms decides whether to exit or not.

3. After the decisions by entrants and exiters in the intermediate good sectors are undertaken, technology producers set the price of their technology.

4. Production in the intermediate and final good sectors take place.

3.4 Benchmark model

Time t is discreet. In this most basic version of the model, I assume that the representative household (consumer) lives for one period. In addition, I also assume that intermediate good producers and technology producers look only one period ahead when making decisions. In the continuous-time version of the model (in Section 3.5), I relax all these assumptions.

3. Note that the assumed timeline of events is not crucial for the results of the paper. The role of the timeline is to impose a structure on the model only. For example, part (3) and part (1) could have been merged: technology producers could announce prices at the time of production, and then firms downstream would make entry/exit decisions. However, it does not matter for the results. Because, given that apart from the purchase of technology, there is no other cost that an entering or exiting firm should incur, it does not matter when the prices are announced, as when the firms downstream make entry/exit decisions, they already take into consideration the price that the upstream firm(s) will set.

3.4.1 Consumers

Consider a one-period lived household with utility function given by:

$$u(c_t) = \frac{c_t^{1-\theta} - 1}{1-\theta} \tag{3.1}$$

where c_t is consumption. There is no population growth, and the total population of workers is L. Each household is endowed with 1 unit of labour, supplies it inelastically and earns wage ω_t.

3.4.2 Final good producers

The unique final good y_t is produced competitively. Other than labour, there is a continuum of intermediate goods of size 1 that is used in the production of the final good. Denote an amount of intermediate good i used in the production of final good y_t at time t by x_{it} and let q_{it} be the quality of that intermediate good at time t. Each intermediate good x_{it} is assumed to depreciate after use, and labour is hired on the spot market.

The final good's production technology is described by the following production function:

$$y_t = L^{1-\alpha} \int_0^1 q_{it}^{1-\alpha} x_{it}^{\alpha} di \tag{3.2}$$

where $\alpha \in (0, 1)$. The final good sector takes the price of x_{it}, denoted by p_{it}, and the wage rate ω_t as given. As intermediate good x_{it} is assumed to depreciate after use and labour is hired on the spot market, the demand for x_{it} is obtained by maximizing the instantaneous profits of a representative final good producer:

$$\max_{[x_{it}]_{i\in[0,1]}, L} \left\{ L^{1-\alpha} \int_0^1 q_{it}^{1-\alpha} x_{it}^{\alpha} di - \int_0^1 x_{it} p_{it} di - \omega_t L \right\}$$

which implies that demand for an intermediate good i is given by:

$$p_{it} = \alpha q_{it}^{1-\alpha} x_{it}^{\alpha-1} L^{1-\alpha} \tag{3.3}$$

3.4.3 Intermediate good producers

Each intermediate good i is produced either by a monopolist, who faces a potential entrant or by two duopolists. Let π_i^{IM} be the profits generated by a monopolist in sector i. If an intermediate good is produced by duopolists, then duopolists collude and each makes a fraction of the monopolist's profits, given by:

$$\pi_i^{ID} = (1 - \Delta^I)\pi_i^{IM} \tag{3.4}$$

where $\Delta^I \in \left[\frac{1}{2}, 1\right]$ is common across i and measures the level of competition among duopolists. In order to see this, consider the extreme values of Δ^I: if $\Delta^I = 1$, then each duopolist makes zero profits, meaning they compete á la Bertrand; and if $\Delta^I = \frac{1}{2}$, duopolists perfectly collude and share equally the monopolist's profits[4].

Given that the constant marginal cost of production is $c > 0$ units of the final good, a monopolist maximizes its profits subject to the demand function given in (3.3):

$$\max_{x_{it}} \left\{ p_{it}x_{it} - x_{it}c \right\} \quad \text{subject} \quad \text{to} \quad p_{it} = \alpha q_{it}^{1-\alpha} x_{it}^{\alpha-1} L^{1-\alpha}$$

which implies that

$$x_{it|q_i} = \left(\frac{\alpha^2}{c}\right)^{\frac{1}{1-\alpha}} q_{it}L; \quad p = \frac{c}{\alpha}; \quad \pi_{it|q_i}^{IM} = \phi c^{-\xi} q_{it} L \tag{3.5}$$

where for notational simplicy I defined $\phi \equiv \frac{1-\alpha}{\alpha}\alpha^{\frac{2}{1-\alpha}}$ and $\xi \equiv \frac{\alpha}{1-\alpha}$.

Let's consider an entry/exit into/from an intermediate good sector. It is well documented both

4. Modelling competition with parameter Δ can seem to be very abstract, as it treats the process of competition as being a "black box" and does not describe explicitly how competition occurs. A more explicit way in which competition could be modelled and a way in which one can think about this "black box" is the following. Suppose that both firms in the market collude, act as a monopolist and set a monopolist price, output etc.. Consequently, the total profits generated in a sector is equal the monopoly profits π^{IM}. Then, firms bargain over this π^{IM} and decide how to divide it. As both firms are identical by construction, each would take half of the monopoly profits. However, despite reaching a bargained agreement, one of the firms may "cheat" on the agreement and decrease the price slightly in an attempt to become a monopolist. In case it happens, the firm that is cheated on immediately realizes it and "punishes" the cheating firm by engaging in Bertrand competition forever, in which both firms make zero profits. Suppose that, from the perspective of one of the firms, $r \in (0, 1)$ is the probability of the other firm cheating; then, the expected profits are $(1-r)\frac{\pi^{IM}}{2}$. Now note that the higher is r, the lower are the expected profits. Although r is not competition, if modelled in this way, it would parametrize the effect of competition. Therefore, higher r corresponds to higher Δ as well.

empirically and theoretically that an entry into an industry reacts positively to high post-entry profits, and exit from an industry reacts positively to low profits (see Siegfried and Evans (1994), Pehrsson (2009) etc.). In other words, this empirical regularity would imply that entry into a sector reacts negatively to high (post-entry) competition levels and exit from an industry reacts positively to high competition levels. In order to see this, consider the following.

When making an entry decision, an entrant compares profits post-entry to earnings pre-entry. Thus, the incentives to enter are determined by the difference between the post- and pre-entry profits. Earnings pre-entry are assumed to be zero for simplicity, and, as specified above, earnings post-entry are $(1 - \Delta^I)\pi_i^{IM}$. Notice that the higher the level of post-entry competition, Δ^I, the lower the difference between the post- and pre-entry profits, and so the lower the incentives to enter. Therefore, the incentives of an entrant entering into an intermediate good sector are decreasing in the level of competition in that sector. I capture this by assuming that the probability of an entrant entering into an intermediate good sector, denoted by ψ, is given by

$$\psi = \overline{\psi} - \varepsilon\Delta^I \tag{3.6}$$

such that $\varepsilon > 0$, $\overline{\psi} > 0$ and $0 \leq \overline{\psi} - \varepsilon\Delta^I \leq 1$[5]. $\overline{\psi}$ captures exogenous factors that can affect the probability of entry into an industry.

Likewise, in an intermediate good industry that is occupied by two firms, there is a probability that one of the firms exits that industry (denoted by λ). As higher competition levels decrease the rents that can be made by staying in a market, the incentives of the firms to stay in a market should decrease competition levels in that market. More precisely, I assume that the higher is Δ^I the higher is the probability of one of the firms exiting an industry. Formally, I impose the following functional form on λ:

$$\lambda = \overline{\lambda} + \upsilon\Delta^I \tag{3.7}$$

5. For this condition to be valid, it must be that $\varepsilon \leq \overline{\psi} \leq 1 + \frac{\varepsilon}{2}$.

where $\upsilon > 0$ and $0 \leq \overline{\lambda} + \upsilon\Delta^I \leq 1$[6]. $\overline{\lambda}$ captures exogenous factors that can affect the probability of exit from an industry.

3.4.4 Technology producers

Each firm producing an intermediate good i obtains technology products from a given *one* technology sector, and also, a given firm in a given technology sector supplies its products to a given *one* (same) intermediate good sector i. Thus, there is a continuum of technology goods of size one as well. An innovation in a technology producer sector, which supplies its technology to a given intermediate good sector i, produces a new level of technology that makes the intermediate good i more productive. More precisely, if there is successful innovation in the technology market, the productivity of the corresponding intermediate good i will go from the last period's value q_{it-1} up to $q_{it} = \kappa q_{it-1}$, where $\kappa > 1$. If there is no successful innovation at t in the technology sector, then $q_{it} = q_{it-1}$. Whenever there is a new technology, the old one becomes obsolete and is not offered for sale.

Any technology-producing industry is managed either by a monopolist or by two oligopolists. Oligopolists are on the same technological level, which means that they produce and supply the same level of technology. If one of the oligopolists innovates successfully, that firm moves one technological step ahead and becomes a monopolist. A monopolist in a technology sector faces a potential entrant, which is one technological step behind the incumbent. I assume that an entrant cannot "leapfrog" the monopolist and derive the latter out of the market immediately. That is, in order to enter the market, an entrant must first innovate and reach the technology level of an incumbent monopolist, in which case a sector turns into a duopoly.

In every period t, a technology-producing monopolist charges a fixed fee to the downstream intermediate good producer(s) to enable the downstream firm(s) to gain access to the latest produced technology. Conditional on the quality level q_i, denote the fixed fee that an upstream technology producer monopolist charges each downstream intermediate firm by $F^D_{i|q_i}$ if the downstream sector

6. For this condition to be valid, it must be that $-\upsilon \leq \overline{\lambda} \leq 1 - \frac{\upsilon}{2}$.

is a duopoly, and by $F^{M}_{i|q_i}$ if the downstream industry is managed by a monopolist. The fee is determined as a result of bargaining between the upstream and downstream firms. More precisely, $F^{M}_{i|q_i}$ is the solution to the following Nash bargaining problem (Nash (1950)):

$$\max_{F^{M}_{i|q_i}} \left(F^{M}_{i|q_i}\right)^{\gamma} \left(\pi^{IM}_{it|q_i} - F^{M}_{i|q_i}\right)^{1-\gamma}$$

where $\gamma \in (0,1)$ is the bargaining power of the upstream (technology producer) monopolist. The solution to this problem is:

$$F^{M}_{i|q_i} = \gamma \pi^{IM}_{it|q_i} = \gamma \phi c^{-\xi} q_{it} L \tag{3.8}$$

In order to determine $F^{D}_{i|q_i}$ I will focus on the bargaining between an upstream monopolist and one of the downstream duopolists. Because the downstream duopolists are identical, the fee charged to both of the duopolists will be the same. $F^{D}_{i|q_i}$ is the solution to the following bargaining problem:

$$\max_{F^{D}_{i|q_i}} \left(F^{D}_{i|q_i}\right)^{\gamma} \left((1-\Delta^{I})\pi^{IM}_{it|q_i} - F^{D}_{i|q_i}\right)^{1-\gamma}$$

which yields to:

$$F^{D}_{i|q_i} = \gamma(1-\Delta^{I})\pi^{IM}_{it|q_i} = \gamma(1-\Delta^{I})\phi c^{-\xi} q_{it} L \tag{3.9}$$

Following Aghion et al. (2005), I assume that knowledge spillovers between the two firms in any technology-producing industry are such that none of the firms can get more than one technological level ahead of the other. That is, if a firm which is one technological step ahead innovates, the firm lagging behind will immediately learn how to copy the leader's previous technology and so remain only one technological step behind. Therefore, at any given time t there are four types of technology-producing sectors: oligopolies, in which the firms are on the same technology level, supplying (1) downstream monopolist or (2) downstream duopolists; and monopolies who face a potential entrant (lagging one technological step behind), supplying (3) a downstream monopolist or (4) downstream duopolists.

As discussed above, the payoff that a monopolist gets from supplying a downstream monopolist or duopolists is $F^M_{i|q_i}$ and $2F^D_{i|q_i}$, correspondingly. Regarding the payoff that each technology producer duopolist gets, I follow the previous approach and assume that duopolists collude and so each duopolist gets $(1-\Delta^T)$ fraction of what the monopolist obtains. More formally, each technology producer duopolist's payoff from supplying technology to a downstream monopolist or duopolists is $(1-\Delta^T)F^M_{i|q_i}$ and $2(1-\Delta^T)F^D_{i|q_i}$ correspondingly, where $\Delta^T \in \left[\frac{1}{2}, 1\right]$ measures the degree of competition among technology producer duopolists.

3.4.5 Equilibrium R&D intensities

If a firm in a technology industry supplying intermediate good sector i spends the R&D cost $\frac{1}{2}q_i n^2$ of the final good, that firm moves one technological step ahead with probability n, where n is R&D intensity of that firm. First, notice that the R&D intensity of a monopolist is zero. Because, as described above, if a monopolist, who is one technological step ahead of an entrant, innovates and moves one more technological step further, an entrant will immediately catch the monopolist's previous technology level. Therefore, it does not pay off the monopolist to innovate. Let n^M_0 and n^D_0 denote the R&D intensities of each firm in an oligopolistic technology sector supplying the downstream monopoly and duopoly, correspondingly. For simplicity of the analysis, in this version of the model, I assume that only one of the oligopolists can innovate at a given time t; this assumption is relaxed in the continuous time version as well, and it does not alter the qualitative results. Define n^M_{-1} and n^D_{-1} to be the R&D intensity of an entrant, which is entering a technology sector supplying the downstream monopoly and duopoly, correspondingly.

The R&D intensities described above are determined by the first-order conditions of symmetric equilibrium, in which each firm maximizes expected profits. The following proposition, proved in Appendix V1, establishes the equilibrium R&D intensities:

Proposition 1. The equilibrium R&D intensities of firms are given by:

$$n^M_0 = \Pi\Big(1+\psi-2\psi\Delta^I\Big)\Big(\kappa+\Delta^T-1\Big) \tag{3.10}$$

$$n_0^D = \Pi\Big(\lambda + 2(1-\lambda)(1-\Delta^I)\Big)\Big(\kappa + \Delta^T - 1\Big) \tag{3.11}$$

$$n_{-1}^M = \Pi\Big(1 - \Delta^T\Big)\Big(1 + \psi - 2\psi\Delta^I\Big) \tag{3.12}$$

$$n_{-1}^D = \Pi\Big(1 - \Delta^T\Big)\Big(\lambda + 2(1-\lambda)(1-\Delta^I)\Big) \tag{3.13}$$

where $\Pi \equiv \gamma\phi c^{-\xi} L$.

Proof: See Appendix V1.

Before moving on to the analysis of the results, it is important to determine further aspects of the model. Let η be the fraction of downstream (intermediate) good sectors that are operated by monopolists and, correspondingly, let $(1-\eta)$ be the fraction of intermediate sectors that are occupied by duopolists. The probability that a monopolist intermediate sector becomes an oligopoly is $\psi\eta$ and the probability that a duopoly intermediate sector turns into a monopoly is $\lambda(1-\eta)$. In steady state, these probabilities must equal each other[7]:

$$\psi\eta = \lambda(1-\eta)$$

which implies that the steady-state fraction of intermediate good sectors that are monopolies is:

$$\eta = \frac{\lambda}{\lambda + \psi} \tag{3.14}$$

Thus, the steady-state average innovation intensity of upstream (technology) sectors that are occu-

7. I.e., the flow of intermediate good sectors that turn into monopolies from being an oligopoly equals the flow of intermediate good sectors that turn into oligopolies from being a monopoly.

pied by duopolists (denoted by $\overline{n}_0$) is given by:

$$\overline{n}_0 = \eta n_0^M + (1-\eta) n_0^D = \frac{\lambda n_0^M + \psi n_0^D}{\lambda + \psi} \tag{3.15}$$

and the steady state average innovation intensity of entrants into upstream (technology) sectors that are occupied by monopolists (denoted by $\overline{n}_{-1}$) is given by:

$$\overline{n}_{-1} = \eta n_{-1}^M + (1-\eta) n_{-1}^D = \frac{\lambda n_{-1}^M + \psi n_{-1}^D}{\lambda + \psi} \tag{3.16}$$

3.4.6 Effect of upstream and downstream competition levels on equilibrium R&D intensities

It can be seen from (3.10) and (3.11) that the effect of competition within innovating firms (technology-producing firms), denoted by Δ^T, positively affects the innovation intensities of oligopolist technology producers. Therefore, the average innovation intensity of oligopolists increases as a result of higher competition among each other. This effect is named "escape-competition effect" in Aghion et al. (2005). The idea is that higher levels of competition induce the oligopolists to innovate, as the incremental value of innovating and becoming a monopolist increases with higher levels of competition. In addition, as it is apparent from (3.12) and (3.13), the innovation intensities chosen by entrants react negatively to the increased post-entry competition upstream (Δ^T). Thus, the average innovation intensity in upstream monopoly sectors declines with higher levels of competition among innovating firms. This is the usual "Schumpeterian effect": as the rents that an entrant can obtain by innovating and entering the market are reduced as a result of higher levels of (post-entry) competition, the incentives of an entrant to innovate decline with higher levels of competition as well.

Regarding the effect of competition levels of the downstream industry on the innovation intensities upstream, it can be said that, under certain conditions, the effect is non-monotonic, more precisely, U-shaped. First, consider the effect of Δ^I on n_0^M, as it is stated in the following proposition:

PROPOSITION 2. The effect of Δ^I on n_0^M is as follows.

If $\frac{2\overline{\psi}}{3} < \varepsilon$, then the relationship between Δ^I and n_0^M is U-shaped:

$$\frac{\partial n_0^M}{\partial \Delta^I} > 0 \quad \text{if} \quad \Delta^I > \frac{1}{4} + \frac{\overline{\psi}}{2\varepsilon} \quad \text{and} \quad \frac{\partial n_0^M}{\partial \Delta^I} < 0 \quad \text{if} \quad \Delta^I < \frac{1}{4} + \frac{\overline{\psi}}{2\varepsilon}$$

If $\frac{2\overline{\psi}}{3} \geq \varepsilon$, then n_0^M is decreasing in Δ^I:

$$\frac{\partial n_0^M}{\partial \Delta^I} < 0$$

PROOF: See Appendix V2.

In order to understand the intuition behind this result, first note that unless downstream firms are perfectly colluding (i.e. $\Delta^I = \frac{1}{2}$), when an entrant enters into a downstream market, it reduces the profits made by each of downstream firms and so it reduces fees charged by an upstream monopolist. Therefore, upstream monopolist dislikes entry downstream unless $\Delta^I = \frac{1}{2}$ in which case it is indifferent. Having this in mind, note that increased competition (i.e. post-entry competition) downstream has two effects: (i) for the reasons described above, it reduces the probability that an entrant enters into a downstream industry, and so has a positive effect on expected profits of an upstream monopolist and (ii) if an entrant enters, it reduces the profits that each oligopolist downstream makes and so decreases the fees that an upstream firm can charge downstream. These two conflicting effects are the ones that are deriving the results.

Consider $\frac{2\overline{\psi}}{3} < \varepsilon$, in which case the relationship is U-shaped. Note the following graph that plots n_0^M and expected profits of an upstream duopolist whose turn it is to innovate (as determined in Appendix V1), for certain values of the parameters[8]:

8. The parameters chosen for this graph are $\Delta^T = 0.7$, $\Pi = 0.4$, $\kappa = 2$, $\overline{\psi} = 2$ and $\varepsilon = 2$. Any $\overline{psi}$ and ε, such that $\frac{2\overline{\psi}}{3} < \varepsilon$ would deliver a similar graph.

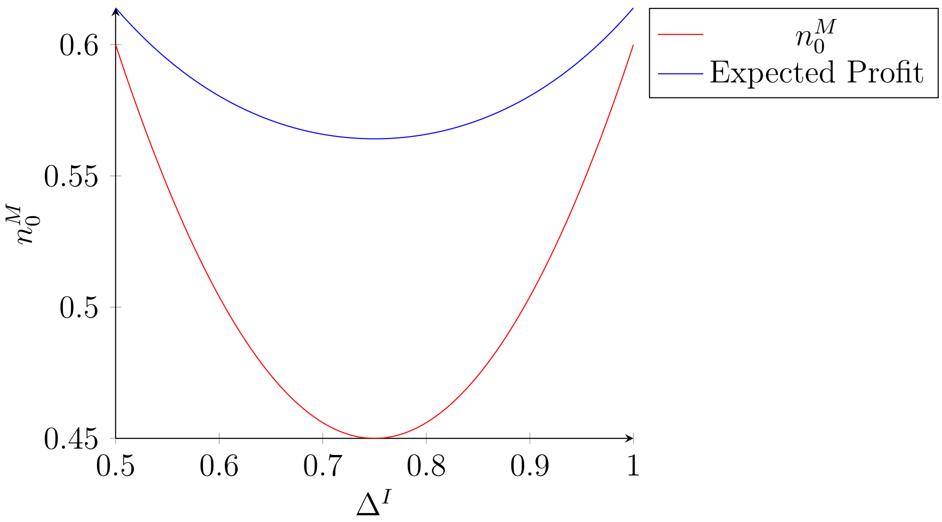


Figure 1 — Effect of downstream competition on upstream innovation intensity, when the downstream industry is occupied by a monopolist, an upstream industry is occupied by two oligopolists and the entry probability downstream is responsive enough to changes in competition levels ($\frac{2\overline{\psi}}{3} < \varepsilon$).

Both functions reach the minimas at the same level of Δ^I. Consider the declining part of both functions to the left of the minimas. Because to the left of the minimas the (post-entry) competition level downstream is quite low, the probability of an entrant entering is high. In case an entrant enters, increasing the level of Δ^I decreases the profits made downstream, and so the fee charged by an upstream firm declines as well. Therefore, given the high entrance probability, the incremental expected profits of an upstream firm are declining to the left of the minimas. Hence, as the expected post-innovation payoffs determine the incentives to innovate, the R&D intensities decline with higher Δ^I to the left of the minimas of the curves as well. However, to the right of the minimas, as the (post-entry) competition level downstream is high, the probability of an entrant entering is low, and with increasing Δ^I, it is declining even more. Therefore, the expected incremental profit of an upstream monopolist and n_0^M start to increase.

Now consider the case when $\frac{2\overline{\psi}}{3} \geq \varepsilon$. In this case the relationship between Δ^I and n_0^M and Δ^I and expected profit is negative, as shown below[9]:

9. The parameters chosen for this graph are $\Delta^T = 0.7$, $\Pi = 0.4$, $\kappa = 2$, $\overline{\psi} = \frac{3}{2}$ and $\varepsilon = 1$. Any $\overline{\psi}$ and ε, such that $\frac{2\overline{\psi}}{3} \geq \varepsilon$, would deliver a similar graph.

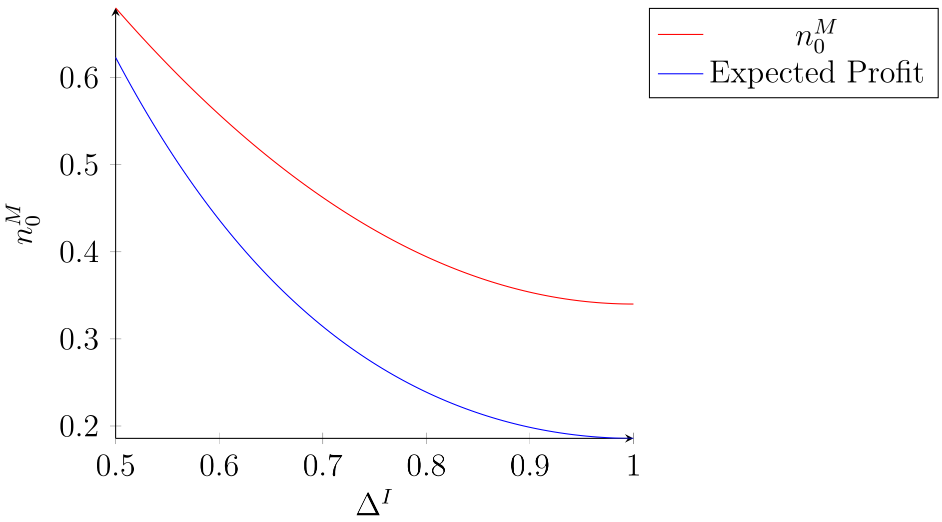


Figure 2 — Effect of downstream competition on upstream innovation intensity, when the downstream industry is occupied by a monopolist, an upstream industry is occupied by two oligopolists and the entry probability downstream is *not* responsive enough to changes in competition levels ($\frac{2\overline{\psi}}{3} > \varepsilon$).

In order to see why $\frac{2\overline{\psi}}{3} \geq \varepsilon$ is generating a different result, recall that what was deriving the U-shape was that at some point the probability of entrance downstream was becoming too low with high levels of Δ^I. In order to generate that result, it was required that $\frac{2\overline{\psi}}{3} < \varepsilon$. In other words, the responsiveness of entrance probability (ψ) to the changes in competition levels (captured by ε) had to be high enough. However, when the responsiveness of entrance probability to the changes in competition levels is low and precisely when $\frac{2\overline{\psi}}{3} \geq \varepsilon$, even at $\Delta^I = 1$ the probability of an entrant entering is never low enough for the expected profits to increase, and so n_0^M declines for all $\Delta \in [\frac{1}{2}, 1]$[10].

The effect of downstream competition on n_0^D is similar to the above case. Consider the following proposition:

Proposition 3. The effect of Δ^I on n_0^D is as follows.

If $\frac{2(1-\overline{\lambda})}{3} < \upsilon$, then the relationship between Δ^I and n_0^M is U-shaped:

10. Note that the *direction* of the effect of Δ^I on n_{-1}^M can be explained in the same way as well, as $n_{-1}^M = n_0^M \frac{1-\Delta^T}{\kappa+\Delta^T-1}$ from (10) and (12).

$$\frac{\partial n_0^D}{\partial \Delta^I} > 0 \quad \text{if} \quad \Delta^I > \frac{1}{4} + \frac{1-\overline{\lambda}}{2\upsilon} \quad \text{and} \quad \frac{\partial n_0^D}{\partial \Delta^I} < 0 \quad \text{if} \quad \Delta^I < \frac{1}{4} + \frac{1-\overline{\lambda}}{2\upsilon} \tag{3.17}$$

If $\frac{2(1-\overline{\lambda})}{3} \geq \upsilon$, then n_0^D is decreasing in Δ^I:

$$\frac{\partial n_0^D}{\partial \Delta^I} < 0$$

Proof: See Appendix V2.

The explanation of this result follows similar reasoning as before, but in this case, the downstream industry is an oligopoly. When one of the oligopolists exits the market, it removes competition from the downstream industry, and so the profits of the remaining downstream firm and the fee charged by an upstream firm increase. Therefore, it is profitable for an upstream firm when one of the downstream oligopolists exits. Having this in mind, an increase in Δ^I has the following two effects: (i) for the reasons described above, it increases the probability that one of the firms downstream exits, and so has a positive effect on expected profits of an upstream firm and (ii) in case if no firm exits, it reduces the profits that each oligopolist downstream makes and so decreases the fees that an upstream firm can charge the downstream ones.

Consider $\frac{2(1-\overline{\lambda})}{3} < \upsilon$. The graph below plots the expected profit of an innovator who faces an oligopolistic downstream market (as specified in Appendix V1), together with the R&D intensities chosen by that innovator[11]:

11. The parameters chosen for this graph are $\Delta^T = 0.7$, $\Pi = 0.4$, $\kappa = 2$, $\overline{\lambda} = -1$ and $\upsilon = 2$. Any $\overline{\lambda}$ and υ, such that $\frac{2(1-\overline{\lambda})}{3} < \upsilon$ would generate a similar graph.

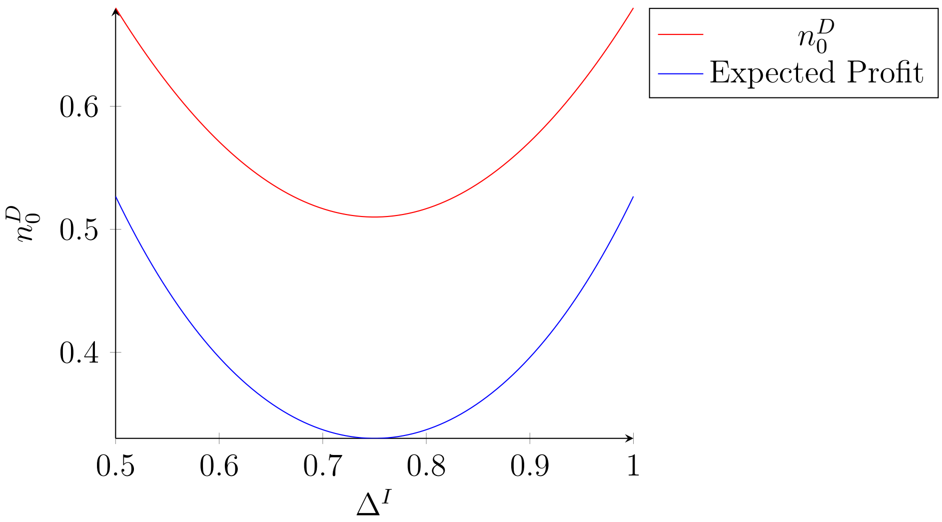


Figure 3 — Effect of downstream competition on upstream innovation intensity, when the downstream and upstream industries are occupied by duopolists and the exit probability downstream is responsive enough to changes in competition levels ($\frac{2(1-\overline{\lambda})}{3} < \upsilon$).

Consider the declining part of the curves to the left of the minimas. In that region, Δ^I is quite low, and so the probability of one of the firms exiting the downstream industry is very low as well. Given such a low exit probability, as with higher Δ^I the profits made downstream and so the fees charged by an upstream firm decline, the expected incremental profits and so R&D intensities decline to the left of minimas. However, to the right of the minimas as the probability of one of the firms downstream exiting is high and it is increasing with higher Δ^I, the expected profits of an upstream innovator increase, which drives up the R&D intensities as well.

The case of $\frac{2(1-\overline{\lambda})}{3} \geq \upsilon$ can be illustrated as[12]:

12. The parameters chosen for this graph are $\Delta^T = 0.7$, $\Pi = 0.4$, $\kappa = 2$, $\overline{\lambda} = -\frac{1}{2}$ and $\upsilon = 1$. Any $\overline{\lambda}$ and υ, such that $\frac{2(1-\overline{\lambda})}{3} \geq \upsilon$ would generate a similar graph.

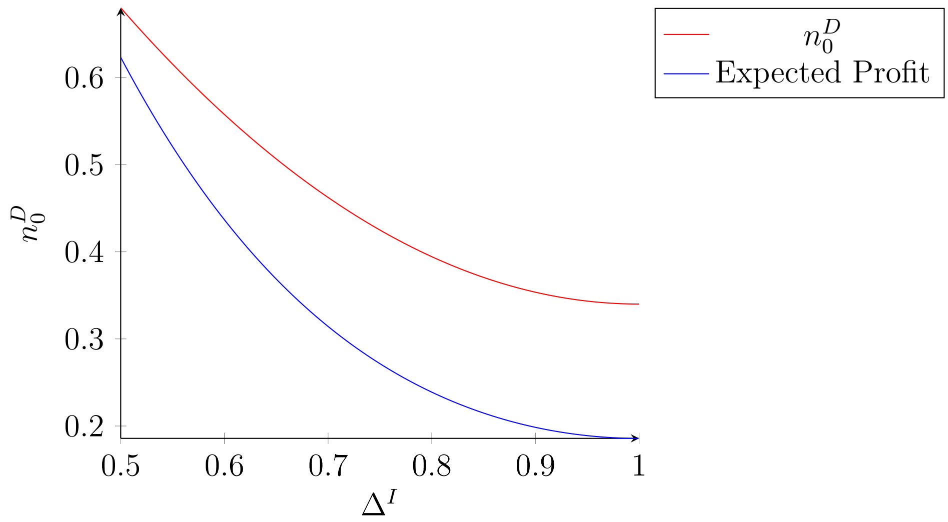


Figure 4 — Effect of downstream competition on upstream innovation intensity, when the downstream and upstream industries are occupied by duopolists and the exit probability downstream is *not* responsive enough to changes in competition levels ($\frac{2(1-\overline{\lambda})}{3} > \upsilon$).

The intuition behind this result is similar to the case of n_0^M. Because $\frac{2(1-\overline{\lambda})}{3} \geq \upsilon$, the probability of an exit of one of the firms downstream is not responsive enough to changes in competition levels. Therefore, λ is never low enough for the expected profits, and so R&D intensities to start to increase[13].

Moreover, the effect of competition among innovating firms on innovation intensities ($\frac{\partial n_z^j}{\Delta^T}$) changes with different values of Δ^I as well. As the R&D intensities are determined by the expected incremental profits of innovators, the direction of the change of $\frac{\partial n_0^j}{\partial \Delta^T}$ follows the pattern of expected profits. I will explain it in the example of n_0^M, but similar reasoning applies to the other case as well.

As was shown above, for the case of $\frac{2\overline{\psi}}{3} < \varepsilon$, the expected profit is convex in Δ^I. Therefore, for low levels of Δ^I, the expected incremental profits that an innovator gets by successfully innovating are decreasing in Δ^I. Thus, an innovator's incentives of innovating and escaping the competition are also decreasing with Δ^I, hence $\frac{\partial n_0^M}{\partial \Delta^T}$ gets lower with higher competition downstream when the competition levels are low. However, when the competition downstream becomes high enough, the

13. Note that the *direction* of the effect of Δ^I on n_{-1}^D can be explained in the same way as well, as $n_{-1}^D = n_0^D \frac{1-\Delta^T}{\kappa+\Delta^T-1}$ from (3.11) and (3.13).

expected profits start to increase. Therefore, the expected incremental profits that an innovator gets by successfully innovating start to increase as well, and so an innovator's incentives to innovate and escape competition start going up. Therefore, when Δ^I is high enough, $\frac{\partial n_0^M}{\partial \Delta^T}$ is increasing in Δ^I. When $\frac{2\overline{\psi}}{3} \geq \varepsilon$, expected profits are decreasing for all $\Delta \in [0.5, 1]$ and so following similar reasoning as above, one can establish that $\frac{\partial n_0^M}{\partial \Delta^T}$ must also be decreasing with higher Δ^I. The graphs below illustrate how $\frac{\partial n_0^M}{\partial \Delta^T}$ changes with Δ^I for $\frac{2\overline{\psi}}{3} \geq \varepsilon$ and $\frac{2\overline{\psi}}{3} < \varepsilon$.

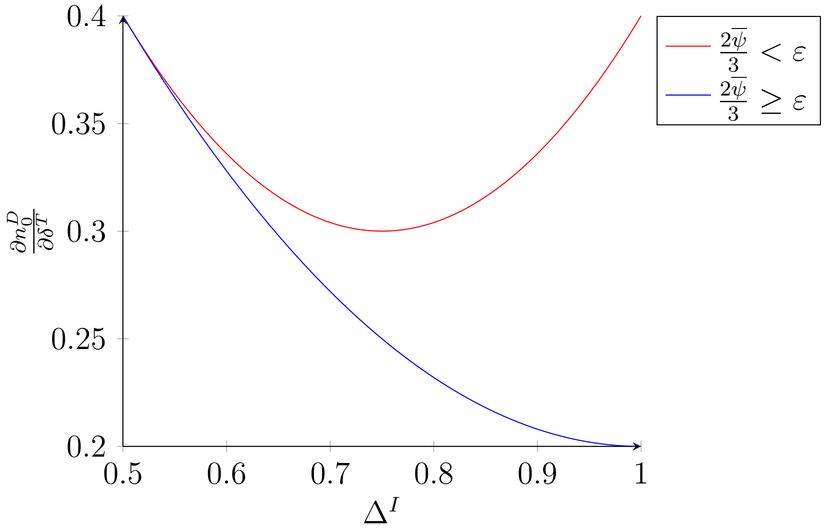


Figure 5 — Change in the magnitude of the "escape-competition effect" as a result of the changing competition levels in a downstream industry.

The effect of changing competition in the intermediate sector on overall (average) innovation intensities is ambiguous but can be shown to be U-shaped for certain parameter values, as stated in the following proposition.

Proposition 4. Let $\overline{n}_0$ and $\overline{n}_{-1}$ be the average innovation intensities in upstream industries that are oligopolies and monopolies correspondingly, as defined in (3.15) and (3.16). The effect of Δ^T on $\overline{n}_0$ is positive and the effect of Δ^T on $\overline{n}_{-1}$ is negative. The effect of Δ^I on both $\overline{n}_0$ and $\overline{n}_{-1}$ is as follows:

for the case when $1 > \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda+\psi)2\psi}{\lambda\varepsilon + \psi\upsilon} < 1 \quad \text{then} \quad \overline{n}_z \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial \overline{n}_z}{\partial \Delta^I} < 0$$

for the case when $1 < \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda + \psi)2\psi}{(\lambda\varepsilon + \psi\upsilon)(2\lambda + 2\upsilon - 1)} < 1 \quad \text{then} \quad \overline{n}_z \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial \overline{n}_z}{\partial \Delta^I} < 0$$

for $z \in \{-1, 0\}$

Proof: See Appendix V3.

3.4.7 Equilibrium growth rate

Let μ be the fraction of monopoly sectors in the technology-producing market, and correspondingly, let $(1-\mu)$ be the fraction of oligopoly sectors in the upstream (technology) market. The probability that a sector moves from being a monopoly to being an oligopoly is $\overline{n}_1\mu$ and the probability that a sector moves from being an oligopoly to being a monopoly is $(1-\mu)\overline{n}_0$. In a steady state, these probabilities are equal to each other:

$$\overline{n}_1\mu = (1-\mu)\overline{n}_0$$

which implies that the steady-state fraction of upstream monopolists is given by:

$$\mu = \frac{\overline{n}_0}{\overline{n}_0 + \overline{n}_{-1}} \tag{3.18}$$

Note that growth in this model is the result of quality improvements of intermediate goods. Denote the average total quality of intermediate goods at time t by q_t and note that it is given by:

$$Q_t = \int_0^1 q_{it} di \tag{3.19}$$

Combining (3.2), (3.5) and (3.19) implies that the total output is given by:

$$y_t = L\left(\frac{\alpha^2}{c}\right)^{\frac{\alpha}{1-\alpha}} Q_t \tag{3.20}$$

Therefore, given that time is discreet, using the above expression, the growth rate of output can be expressed as:

$$g = \frac{y_{t+1} - y_t}{y_t} = \frac{Q_{t+1} - Q_t}{Q_t} \tag{3.21}$$

Consider the quality improvements in an intermediate industry i. First, note that successful innovations in the corresponding technology sector improve an intermediate good's quality if the technology sector is occupied by duopolists. The reason for this is that because entrants only learn how to copy the existing technology of an incumbent monopolist, they do not produce *new* levels of technology. Therefore, the quality of an intermediate good i becomes $q_{it+1} = \kappa q_i$ with probability $(1-\mu)\overline{n}_0$. Overall, for a given intermediate good, the quality follows the following rule[14]:

$$q_{it+1} = \begin{cases} \kappa q_{it} & \text{with} \quad \text{probability} \quad (1-\mu)\overline{n}_0 \\ q_{it} & \text{with} \quad \text{probability} \quad 1-(1-\mu)\overline{n}_0 \end{cases} \tag{3.22}$$

Thus, the expected average total quality of intermediate goods at time $t+1$ is given by:

$$Q_{t+1} = \int_0^1 \Big((1-\mu)\overline{n}_0\Big)\kappa q_{it} di + \int_0^1 \Big(1-(1-\mu)\overline{n}_0\Big) q_{it} di \tag{3.23}$$

Using (3.21), the steady-state growth rate is obtained as being:

$$g^* = \big(1-\mu\big)\big(\kappa-1\big)\overline{n}_0 \tag{3.24}$$

14. The probability of the quality not improving, namely $1-(1-\mu)\overline{n}_0$, can also be derived in the following way. Innovations do not happen if a technology sector is occupied by duopolists, but they fail to innovate, which happens with probability $(1-\mu)(1-\overline{n}_0)$, and if the technology sector is occupied by a monopolist, which happens with probability μ. Putting these two together implies that the probability of the quality not improving is $(1-\mu)(1-\overline{n}_0)+\mu = 1-(1-\mu)\overline{n}_0$.

As was shown in Proposition 4, $\overline{n}_0$ is increasing in Δ^I. Therefore, the growth rate is increasing with high levels of competition among innovating firms. Regarding the effect of Δ^I on the growth rate, the relationship follows exactly the same pattern as $\frac{\partial \overline{n}_0}{\partial \Delta^I}$, which is highlighted in Proposition 4. The following Proposition summarizes the effect of competition on the growth rate

Proposition 5. Let g be the equilibrium growth rate of the final output, as defined in (3.24). The effect of Δ^T on g is positive. The effect of Δ^I on g is as follows:

for the case when $1 > \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda+\psi)2\psi}{\lambda\varepsilon + \psi\upsilon} < 1 \quad \text{then} \quad g \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial g}{\partial \Delta^I} < 0$$

for the case when $1 < \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda+\psi)2\psi}{(\lambda\varepsilon + \psi\upsilon)(2\lambda + 2\upsilon - 1)} < 1 \quad \text{then} \quad g \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial g}{\partial \Delta^I} < 0$$

Proof: See Appendix V4.

3.5 Model in continuous time

In this section, I relax the assumptions that the representative household lives for one period and that intermediate goods and technology producers only look one period ahead. The structure of the economy remains as described in Section 3.4.

3.5.1 Consumers

Consider an infinitely lived representative household with preferences

$$\int_0^\infty \exp(-\rho^c t)\frac{C_t^{1-\theta}-1}{1-\theta}dt \tag{3.25}$$

where $\rho^c > 0$ is the household's discount factor. Maximization of the household's lifetime utility function subject to inter-temporal budget constraint yields the usual Euler equation:

$$\frac{\dot{C}_t}{C_t} = \frac{1}{\theta}\big(r_t - \rho\big) \tag{3.26}$$

where r_t is the real interest rate at time t. As before, the total population of workers is L and each household is endowed with 1 unit of labour and supplies it inelastically at wage rate ω_t.

3.5.2 Final good producers

I retain the assumption that the final good sector is competitive. The aggregate production function is given by

$$Y_t = L^{1-\alpha}\int_0^1 q_{it}^{1-\alpha}x_{it}^{\alpha}di$$

The intermediate input x_{it} is, again, assumed to depreciate after use at time t and labour is hired on the spot market. This assumption enables me to obtain demand for x_{it} and for labour by maximizing the instantaneous profits of a representative final good producer, as was done in the last section. Therefore, the demand for x_{it} is, as before, given by:

$$p_{it} = \alpha q_{it}^{1-\alpha}x_{it}^{\alpha-1}L^{1-\alpha}$$

3.5.3 Intermediate good producers

The structure of intermediate good sectors remains as before. Note that the demand that an intermediate good monopolist faces is not intertemporal, and there are no other intertemporal features of the decision-making process of an intermediate good monopolist. Therefore, the amount of x_{it} supplied, the price of an intermediate input and the profits of an intermediate input monopolist can be obtained by maximizing the instantaneous profits of a monopolist, as it was done in Section 3.4. The solution to the maximization is given in (3.5):

$$x_{it|q_i} = \left(\frac{\alpha^2}{c}\right)^{\frac{1}{1-\alpha}} q_{it}L; \quad p = \frac{c}{\alpha}; \quad \pi^{IM}_{it|q_i} = \phi c^{-\xi} q_{it} L$$

If an intermediate good sector i is occupied by duopolists, each duopolist makes $(1 - \Delta^I)\pi^{IM}_{it|q_i}$. The probabilities of an entrant entering into a monopoly intermediate sector and the probability of one of the firms exiting a duopoly sector remain as in (3.6) and (3.7).

3.5.4 Technology producers

The structure of the technology-producing sectors remains as before, but there are several issues that need to be addressed due to the continuous time environment. Given that both downstream and upstream firms are looking forward not only to one period as before but infinitely many periods ahead, the bargaining process that determines the fee charged by an upstream monopolist takes a form of bargaining with alternating offers. However, determining the fees charged by an upstream monopolist imposes a difficulty in the continuous time model. The reason is that there are technical difficulties when one attempts to model a bargaining game (with alternating offers) in continuous time, as described in Simon and Stinchcombe (1989), Bergin and MacLeod (1993), Ortner (2019) and other papers. Several modelling techniques have been proposed, and in this paper, I will follow the one proposed by Perry and Reny (1993).

As before, conditional on quality level q_i, denote the fee charged by an upstream monopolist to a downstream monopolist and a duopolist at time t by $F^M_{it|q_i}$ and $F^D_{it|q_i}$, respectively.

First, consider the bargaining process between upstream and downstream monopolists. The bargaining process goes as follows. Each firm makes the other an offer of $F^M_{i|q_i}$. Once a firm h

($h \in \{U, Do\}$[15]) makes an offer at any time, that firm cannot make another offer until $\chi_h > 0$ units of time has passed (it is called "waiting time" in Perry and Reny (1993)). In addition, when a firm $-h$ makes an offer to h, the amount of time required for h to react to that offer is denoted by l_h (it is called a "reaction time"). The bargaining ends with an agreement if, at some finite time, t, the firms' offers coincide; otherwise, there is no agreement. Let ρ^h be the discount rate of firm h.

Perry and Reny (1993) show that if the reaction times of both firms are zero (i.e. $l_U = l_D = 0$), then the subgame perfect equilibrium of the above-described game in continuous time corresponds to the one specified in Rubinstein (1982). Namely, as the bargaining is going over the profits of the downstream firm, the agreement is reached immediately, and the outcome is

$$F^M_{it|q_i} = \pi^{IM}_{it|q_i} \left[\frac{1 - \exp(\rho^D \chi_U)}{1 - \exp(\rho^D \chi_U + \rho^U \chi_D)} \right] \tag{3.27}$$

In this text, I will maintain the assumption that $l_U = l_D = 0$, and so the fee that an upstream monopolist charges downstream is given as in (3.27).

Regarding the bargaining between an upstream monopolist and one of the downstream duopolists, let χ_h, ρ^h and l_h remain as in the previous bargaining problem. Then, the fee that an upstream monopolist charges one of the downstream duopolists is:

$$F^D_{it|q_i} = \left(1 - \Delta^I\right) \pi^{IM}_{it|q_i} \left[\frac{1 - \exp(\rho^D \chi_U)}{1 - \exp(\rho^D \chi_U + \rho^U \chi_D)} \right] \tag{3.28}$$

As $\frac{1-\exp(\rho^D \chi_U)}{1-\exp(\rho^D \chi_U + \rho^U \chi_D)}$ is a constant, for notational simplicity, I will denote it by Λ in the text below.

3.5.5 Solving for equilibrium R&D intensities in continuous time

Given the fees (i.e. upstream monopoly profits) determined above, recall that if an upstream sector is occupied by duopolists, each duopolist makes $\left(1 - \Delta^T\right) F^j_{it|q_i}$ for $h \in \{M, D\}$. Also, in order

15. U stands for "Upstream" and Do stands for "Downstream".

to obtain an R&D intensity n, a technology-producing firm supplying a downstream intermediate sector i has to spend $\frac{1}{2}q_i n^2$ of the final good.

Given that firms are forward-looking, to solve for the R&D research intensities n_0^M, n_0^D, n_{-1}^M and n_{-1}^D, I will use Bellman equations. Also, I relax the assumption that only one of the firms in a duopoly technology sector can innovate. For notational clarity, denote the R&D intensity chosen by the rival firm in an upstream duopoly by $\tilde{n}_0^j$, which is taken as given.

Let V_1^{ij}, V_0^{ij} and V_{-1}^{ij} for $j \in \{M, D\}$ be the steady state values of being an upstream monopolist, oligopolist and an entrant respectively and supplying a downstream industry i, when that downstream industry is in state j[16]. As before, denote $q_i' = \kappa q_i$ for $\kappa > 1$. The following proposition establishes the R&D intensities chosen by upstream firms.

Proposition 6. The (symmetric) equilibrium R&D intensities of upstream firms and the steady-state values of being an upstream monopolist, oligopolist and an entrant are the solutions to the following system of non-linear equations :

$$\tilde{r}V_1^{iM} = \tilde{\Pi} + n_{-1}^M\left(\psi\left(V_0^{iD} - V_1^{iM}\right) + \left(1-\psi\right)\left(V_0^{iM} - V_1^{iM}\right)\right) \tag{3.29}$$

$$\tilde{r}V_1^{iD} = 2\left(1 - \Delta^I\right)\tilde{\Pi} + n_{-1}^D\left(\lambda\left(V_0^{iM} - V_1^{iD}\right) + \left(1-\lambda\right)\left(V_0^{iD} - V_1^{iD}\right)\right) \tag{3.30}$$

$$\tilde{r}V_{-1}^{iM} = n_{-1}^M\left(\psi\left(V_0^{iD} - V_{-1}^{iM}\right) + \left(1-\psi\right)\left(V_0^{iM} - V_{-1}^{iM}\right)\right) - \frac{1}{2}(n_{-1}^M)^2 \tag{3.31}$$

$$\tilde{r}V_{-1}^{iD} = n_{-1}^D\left(\lambda\left(V_0^{iM} - V_{-1}^{iD}\right) + \left(1-\lambda\right)\left(V_0^{iD} - V_{-1}^{iD}\right)\right) - \frac{1}{2}\left(n_{-1}^D\right)^2 \tag{3.32}$$

16. M stands for "Monopoly" and D stands for "Duopoly".

$$
\begin{aligned}
\tilde{r}V_0^{iM} = &\Big(1-\Delta^T\Big)\tilde{\Pi} + n_0^M\kappa\Bigg(\psi\Big(V_1^{iD}-V_0^{iM}\Big)+\Big(1-\psi\Big)\Big(V_1^{iM}-V_0^{iM}\Big)\Bigg) \\
&+\tilde{n}_0^M\kappa\Bigg(\psi\Big(V_{-1}^{iD}-V_0^{iM}\Big)+\Big(1-\psi\Big)\Big(V_{-1}^{iM}-V_0^{iM}\Big)\Bigg)-\tfrac{1}{2}\Big(n_0^M\Big)^2
\end{aligned}
\tag{3.33}
$$

$$
\begin{aligned}
\tilde{r}V_0^{iD} = &\; 2\Big(1-\Delta^T\Big)\Big(1-\Delta^I\Big)\tilde{\Pi} + n_0^D\kappa\Bigg(\lambda\Big(V_1^{iM}-V_0^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_1^{iD}-V_0^{iD}\Big)\Bigg) \\
&+\tilde{n}_0^D\kappa\Bigg(\lambda\Big(V_{-1}^{iM}-V_0^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_{-1}^{iD}-V_0^{iD}\Big)\Bigg)-\tfrac{1}{2}\Big(n_0^D\Big)^2
\end{aligned}
\tag{3.34}
$$

$$
n_{-1}^M = \psi\Big(V_0^{iD}-V_{-1}^{iM}\Big)+\Big(1-\psi\Big)\Big(V_0^{iM}-V_{-1}^{iM}\Big) \tag{3.35}
$$

$$
n_{-1}^D = \lambda\Big(V_0^{iM}-V_{-1}^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_0^{iD}-V_{-1}^{iD}\Big) \tag{3.36}
$$

$$
n_0^M = \kappa\Bigg(\psi\Big(V_1^{iD}-V_0^{iM}\Big)+\Big(1-\psi\Big)\Big(V_1^{iM}-V_0^{iM}\Big)\Bigg) \tag{3.37}
$$

$$
n_0^D = \kappa\Bigg(\lambda\Big(V_1^{iM}-V_0^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_1^{iD}-V_0^{iD}\Big)\Bigg) \tag{3.38}
$$

where $\tilde{\Pi} \equiv \Lambda\phi c^{-\xi}L$.

Proof: See Appendix V5.

3.5.6 Effect of upstream and downstream competition levels on equilibrium R&D intensities in continuous time

In order to analyze the effect of Δ^I and Δ^T on equilibrium R&D intensities, I solve numerically the above system for different values of Δ^I and Δ^T, given the values of other parameters. The process of simplification of the above system of non-linear equations is described in Appendix V6.

First, consider the effect of competition among innovating firms Δ^T on R&D intensities. The graphs in Appendix V7 show the numerical results of how n_z^j for $z \in \{0, 1\}$ and $j \in \{M, D\}$ change with different values of Δ^T and how the relationship between Δ^T and n_z^j change with different values of Δ^I[17]. I show the results for both the cases of $\frac{3\overline{\psi}}{2} < \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} < \upsilon$ and $\frac{3\overline{\psi}}{2} \geq \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$[18].

Consistently with the discrete-time model, in both cases of $\frac{3\overline{\psi}}{2} < \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} < \upsilon$ and $\frac{3\overline{\psi}}{2} \geq \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$, the R&D intensities chosen by an entrant decreases with higher level of Δ^T (Schumpeterian effect) and the innovation intensities of oligopolists react positively to higher levels of competition (escape-competition effect). When $\frac{3\overline{\psi}}{2} < \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} < \upsilon$, as was predicted in discrete time model, $\frac{\partial n_0^j}{\partial \Delta^T}$ first decreases (i.e. $\frac{\partial n_0^j}{\partial \Delta^T}$ curve shifts down)and then increases (shifts up) with higher levels of Δ^I. However, when $\frac{3\overline{\psi}}{2} \geq \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$, $\frac{\partial n_0^j}{\partial \Delta^T}$ decreases with higher values of Δ^I, as was the case in discrete time model as well.

For comparison, in the last sub-section of the same appendix, I also present the simulation results for the effect of Δ^T on n_z^j for $\frac{3\overline{\psi}}{2} < \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$. In this case, n_{-1}^M and n_{-1}^D differ significantly, so I present them on different plots. As before n_{-1}^j decrease with higher Δ^T and n_0^j increase with higher levels of upstream competition. However, regarding how $\frac{\partial n_0^j}{\partial \Delta^T}$ changes with Δ^I, the answer is not clear. As can be seen from the plots, in some cases, it follows a U-shape (e.g. in the case of n_0^M), and in some other cases, it is decreasing (as for n_0^D).

Now consider the effect of downstream competition levels Δ^I on R&D intensities of upstream firms. The graphs in Appendix V8 show the numerical results of how Δ^I affects n_z^j for $z \in \{0, 1\}$ and $j \in \{M, D\}$ for different values of Δ^T. As before, I present three cases: (i) $\frac{3\overline{\psi}}{2} < \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} < \upsilon$; (ii) $\frac{3\overline{\psi}}{2} \geq \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$ and (iii) Δ^T on n_z^j for $\frac{3\overline{\psi}}{2} < \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$.

First consider the case of $\frac{3\overline{\psi}}{2} < \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} < \upsilon$. As can be seen from the graphs (more obviously from the graphs of n_0^j), consistently with the predictions of the discrete-time model, the effect of downstream firm competition on R&D intensities of upstream firms is U-shaped. In addition,

17. Due to chosen parameters, the values of n_{-1}^M and n_{-1}^D and the patterns of the change are very similar. Therefore, I only show the results for one of them

18. In all numerical simulations for the case of $\frac{3\overline{\psi}}{2} < \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} < \upsilon$ I choose $\overline{\psi} = 2$, $\varepsilon = 2$, $\overline{\lambda} = -1$ and $\upsilon = 2$. For $\frac{3\overline{\psi}}{2} \geq \varepsilon$, $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$ I choose $\overline{\psi} = 3/2$, $\varepsilon = 1$, $\overline{\lambda} = -1/2$ and $\upsilon = 1$. The other parameters are chosen to be $\tilde{\Pi} = 0.4$ and $\kappa = 2$.

changes in the level of Δ^T linearly alter the effect of Δ^I on n_z^j.

When $\frac{3\overline{\psi}}{2} \geq \varepsilon$ and $\frac{3(1-\bar{\lambda})}{2} \geq \upsilon$, the R&D intensities decline with higher Δ^I, as was predicted in the discrete time model. Finally, when $\frac{3\overline{\psi}}{2} < \varepsilon$ and $\frac{3(1-\bar{\lambda})}{2} \geq \upsilon$, the pattern of the change varies over R&D intensities. Some, such as n_0^M, are convex in Δ^I, but others, such as n_0^D, are declining in Δ^I.

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Appendix for Chapter 3

Appendix V1: Proof of Proposition 1

Consider first a technology sector occupied by duopolists supplying a downstream monopolist. If an oligopolist, whose turn it is to innovate, innovates successfully (with probability n_0^M), the intermediate input's quality moves one step up and becomes κq_i. In addition, the innovating firm becomes a monopolist and obtains a monopolist's profits given by $\gamma\phi c^{-\xi}\kappa q_i L$ with probability $(1-\psi)$ and $2\gamma(1-\Delta^I)\phi c^{-\xi}\kappa q_i L$ with probability ψ. However, if an innovating firm cannot successfully innovate (with probability $(1-n_0^M)$), then the quality of an intermediate remains at q_i and the technology sector stays as an oligopoly in which both firms make $(1-\Delta^T)\gamma\phi c^{-\xi}q_i L$ with probability $(1-\psi)$ and $(1-\Delta^T)2\gamma(1-\Delta^I)\phi c^{-\xi}q_i L$ with probability ψ. Thus, an innovating oligopolist upstream, supplying a downstream monopolist, chooses n_0^M to maximize the following expected profit:

$$\max_{n_0^M}\Bigg\{n_0^M\Big[(1-\psi)\gamma\phi c^{-\xi}\kappa q_i L+\psi 2\gamma(1-\Delta^I)\phi c^{-\xi}\kappa q_i L\Big] \\ +\big(1-n_0^M\big)\big(1-\Delta^T\big)\Big[(1-\psi)\gamma\phi c^{-\xi}q_i L+\psi 2\gamma(1-\Delta^I)\phi c^{-\xi}q_i L\Big]-\frac{1}{2}q_i(n_0^M)^2\Bigg\}$$

which implies that:

$$n_0^M=\Pi\Big(1+\psi-2\psi\Delta^I\Big)\Big(\kappa+\Delta^T-1\Big) \tag{3.39}$$

where $\Pi\equiv\gamma\phi c^{-\xi}L$.

Likewise, following similar reasoning, the innovation intensity chosen by an oligopolist who is supplying a downstream duopoly maximizes the following expected profit:

$$\max_{n_0^D} \Bigg\{ n_0^D \Big[\lambda\gamma\phi c^{-\xi}\kappa q_i L + (1-\lambda)2\gamma(1-\Delta^I)\phi c^{-\xi}\kappa q_i L \Big]$$
$$+ \big(1-n_0^D\big)\big(1-\Delta^T\big)\Big[\lambda\gamma\phi c^{-\xi} q_i L + (1-\lambda)2\gamma(1-\Delta^I)\phi c^{-\xi} q_i L\Big] - \frac{1}{2} q_i (n_0^D)^2 \Bigg\}$$

which implies:

$$n_0^D = \Pi\Big(\lambda + 2(1-\lambda)(1-\Delta^I)\Big)\Big(\kappa + \Delta^T - 1\Big) \tag{3.40}$$

Consider an entrant entering a technology sector that supplies a downstream monopolist. With probability n_{-1}^M, an entrant successfully innovates, copies an incumbent monopolist's profits and enters into the technology sector, turning it into an oligopoly. In this case each firm makes $(1-\Delta^T)\gamma\phi c^{-\xi} q_i L$ with probability $(1-\psi)$ and $(1-\Delta^T)2\gamma(1-\Delta^I)\phi c^{-\xi} q_i L$ with probability ψ. With probability $(1-n_{-1}^M)$, an entrant cannot innovate successfully, and so it stays outside of the market, making zero profits. Thus, n_{-1}^M is chosen to maximize:

$$\max_{n_{-1}^M} \Bigg\{ n_{-1}^M \big(1-\Delta^T\big)\Big[(1-\psi)\gamma\phi c^{-\xi} q_i L + \psi 2\gamma(1-\Delta^I)\phi c^{-\xi} q_i L\Big] - \frac{1}{2} q_i (n_{-1}^M)^2 \Bigg\}$$

$$n_{-1}^M = \Pi\Big(1-\Delta^T\Big)\Big(1+\psi-2\psi\Delta^I\Big) \tag{3.41}$$

Similarly, n_{-1}^D is chosen to solve:

$$\max_{n_{-1}^D} \Bigg\{ n_{-1}^D \big(1-\Delta^T\big)\Big[\lambda\gamma\phi c^{-\xi} q_i L + (1-\lambda)2\gamma(1-\Delta^I)\phi c^{-\xi} q_i L\Big] - \frac{1}{2} q_i (n_{-1}^D)^2 \Bigg\}$$

$$n_{-1}^D = \Pi\Big(1-\Delta^T\Big)\Big(\lambda + 2(1-\lambda)(1-\Delta^I)\Big) \tag{3.42}$$

Q.E.D.

Appendix V2: Proofs of Propositions 2 and 3

Proof of Proposition 2:

Differentiating (3.10) with respect to Δ^I implies:

$$\frac{\partial n_0^M}{\partial \Delta^I} = \left[- \frac{d\psi}{d\Delta^I}\Big(2\Delta^I - 1\Big) - 2\psi \right] \Pi \left(\kappa + \Delta^T - 1 \right) \tag{3.43}$$

from the above, it can be shown that:

$$\frac{\partial n_0^M}{\partial \Delta^I} > 0 \quad \text{if} \quad \Delta^I > \frac{1}{4} + \frac{\overline{\psi}}{2\varepsilon} \quad \text{and} \quad \frac{\partial n_0^M}{\partial \Delta^I} < 0 \quad \text{if} \quad \Delta^I < \frac{1}{4} + \frac{\overline{\psi}}{2\varepsilon} \tag{3.44}$$

However note that, given $\Delta^I \in \left[\frac{1}{2}, 1\right]$, for $\Delta^I > \frac{1}{4} + \frac{\overline{\psi}}{2\varepsilon}$ to be valid it must be that $\frac{1}{4} + \frac{\overline{\psi}}{2\varepsilon} < 1 \Leftrightarrow \frac{2\overline{\psi}}{3} < \varepsilon$. Otherwise, if $\frac{2\overline{\psi}}{3} \geq \varepsilon$ there is no such Δ^I for which $\frac{\partial n_0^M}{\partial \Delta^I} > 0$.

Q.E.D.

Proof of Proposition 3:

Differentiating (3.11) with respect to Δ^I implies:

$$\frac{\partial n_0^D}{\partial \Delta^I} = \left[\frac{d\lambda}{d\Delta^I}\Big(2\Delta^I - 1\Big) - 2\Big(1 - \lambda\Big) \right] \Pi \left(\kappa + \Delta^T - 1 \right) \tag{3.45}$$

from the above, it can be shown that

$$\frac{\partial n_0^D}{\partial \Delta^I} > 0 \quad \text{if} \quad \Delta^I > \frac{1}{4} + \frac{1 - \overline{\lambda}}{2\upsilon} \quad \text{and} \quad \frac{\partial n_0^D}{\partial \Delta^I} < 0 \quad \text{if} \quad \Delta^I < \frac{1}{4} + \frac{1 - \overline{\lambda}}{2\upsilon} \tag{3.46}$$

However note that, given $\Delta^I \in \left[\frac{1}{2}, 1\right]$, for $\Delta^I > \frac{1}{4} + \frac{1-\overline{\lambda}}{2\upsilon}$ to be valid it must be that $\frac{1}{4} + \frac{1-\overline{\lambda}}{2\upsilon} < 1 \Leftrightarrow \frac{2(1-\overline{\lambda})}{3} < \upsilon$. Otherwise, if $\frac{2(1-\overline{\lambda})}{3} \geq \upsilon$, there is no such Δ^I for which $\frac{\partial n_0^M}{\partial \Delta^I} > 0$.

Q.E.D.

Appendix V3: Proof of Proposition 4

Recall the average equilibrium R&D intensities:

$$\overline{n}_0 = \frac{\lambda n_0^M + \psi n_0^D}{\lambda + \psi}$$

$$\overline{n}_{-1} = \frac{\lambda n_{-1}^M + \psi n_{-1}^D}{\lambda + \psi}$$

Differentiating the above functions with respect to Δ^T yields:

$$\frac{\partial \overline{n}_0}{\partial \Delta^T} = \frac{\lambda \frac{\partial n_0^M}{\partial \Delta^T} + \psi \frac{\partial n_0^D}{\partial \Delta^T}}{\lambda + \psi} \geq 0$$

as $\frac{\partial n_0^M}{\partial \Delta^T} \geq 0$ and $\frac{\partial n_0^D}{\partial \Delta^T} \geq 0$.

Similarly:

$$\frac{\partial \overline{n}_{-1}}{\partial \Delta^T} = \frac{\lambda \frac{\partial n_{-1}^M}{\partial \Delta^T} + \psi \frac{\partial n_{-1}^D}{\partial \Delta^T}}{\lambda + \psi} \leq 0$$

as $\frac{\partial n_{-1}^M}{\partial \Delta^T} \leq 0$ and $\frac{\partial n_{-1}^D}{\partial \Delta^T} \leq 0$.

Regarding the effect of Δ^I on average R&D intensities, I will prove the result for $\overline{n}_0$ only, as the result for $\overline{n}_{-1}$ can be proved in exactly same way. Because, as can be seen from (3.10)-(3.13) and (3.15)-(3.16), $\overline{n}_{-1} = s\overline{n}_0$ for $s \in (0, 1)$.

Differentiating $\overline{n}_0$ with respect to Δ^I yields to:

$$\frac{\partial \overline{n}_0}{\partial \Delta^I} = \frac{1}{\lambda^2 + \psi^2} \left\{ \left[\lambda + \psi \right] \left[\lambda \frac{\partial n_0^M}{\partial \Delta^I} + \psi \frac{\partial n_0^D}{\partial \Delta^I} \right] + \left[\varepsilon \lambda + \upsilon \psi \right] \left[n_0^M - n_0^D \right] \right\}$$

using the result of Proposition 1 one can show that:

$$n_0^M - n_0^D = \Pi(\kappa + \Delta^T - 1)(1 - \lambda - \psi)(2\Delta^I - 1)$$

substitute the above into $\frac{\partial \overline{n}_0}{\partial \Delta^I}$:

$$\frac{\partial \overline{n}_0}{\partial \Delta^I} = \frac{1}{\lambda^2+\psi^2}\Bigg\{\Bigg[\lambda+\psi\Bigg]\Bigg[\lambda\frac{\partial n_0^M}{\partial \Delta^I}+\psi\frac{\partial n_0^D}{\partial \Delta^I}\Bigg]+\Bigg[\varepsilon\lambda+\upsilon\psi\Bigg]\Pi\Bigg[\kappa+\Delta^T-1\Bigg]\Bigg[1-\lambda-\psi\Bigg]\Bigg[2\Delta^I-1\Bigg]\Bigg\}$$

Recall that:

$$\frac{\partial n_0^M}{\partial \Delta^I} = \Bigg[\varepsilon\Big(2\Delta^I-1\Big)-2\psi\Bigg]\Pi\Bigg(\kappa+\Delta^T-1\Bigg)$$

$$\frac{\partial n_0^D}{\partial \Delta^I} = \Bigg[\upsilon\Big(2\Delta^I-1\Big)-2\Big(1-\lambda\Big)\Bigg]\Pi\Bigg(\kappa+\Delta^T-1\Bigg)$$

For $1 > \lambda+\psi$ plugging these back into $\frac{\partial \overline{n}_0}{\partial \Delta^I}$ yields to:

$$\frac{\partial \overline{n}_0}{\partial \Delta^I} = \frac{1}{\lambda^2+\psi^2}\Pi\Big(\kappa+\Delta^T-1\Big)\Bigg\{\Big(2\Delta^I-1\Big)\Big(\lambda\varepsilon+\psi\upsilon\Big)-\Big(\lambda+\psi\Big)2\psi\Bigg\}$$

Thus, if

$$\frac{1}{2}+\frac{1}{2}\frac{(\lambda+\psi)2\psi}{\lambda\varepsilon+\psi\upsilon} < 1$$

then $\frac{\partial \overline{n}_0}{\partial \Delta^I}$ is U-shaped. Otherwise, $\frac{\partial \overline{n}_0}{\partial \Delta^I} < 0$.

In addition, if $1 < \lambda+\psi$, $\frac{\partial \overline{n}_0}{\partial \Delta^I}$ becomes:

$$\frac{\partial \overline{n}_0}{\partial \Delta^I} = \frac{1}{\lambda^2+\psi^2}\Pi\Big(\kappa+\Delta^T-1\Big)\Bigg\{\Big(2\Delta^I-1\Big)\Big(\lambda\varepsilon+\psi\upsilon\Big)\Big(2\lambda+2\upsilon-1\Big)-\Big(\lambda+\psi\Big)2\psi\Bigg\}$$

and so if

$$\frac{1}{2}+\frac{1}{2}\frac{(\lambda+\psi)2\psi}{(\lambda\varepsilon+\psi\upsilon)(2\lambda+2\upsilon-1)} < 1$$

then $\frac{\partial \overline{n}_0}{\partial \Delta^I}$ is U-shaped. Otherwise, $\frac{\partial \overline{n}_0}{\partial \Delta^I} < 0$.

Q.E.D.

Appendix V4: Proof of proposition 5

Recall that

$$g = (1-\mu)(\kappa-1)\overline{n}_0$$

where

$$\mu = \frac{\overline{n}_0}{\overline{n}_0 + \overline{n}_{-1}}$$

Differentiating g with respect to Δ^T yields to:

$$\frac{\partial g}{\partial \Delta^T} = -\frac{\partial \mu}{\partial \Delta^T}(\kappa-1)\overline{n}_0 + (1-\mu)(\kappa-1)\frac{\partial \overline{n}_0}{\partial \Delta^T}$$

and similarly,

$$\frac{\partial g}{\partial \Delta^I} = -\frac{\partial \mu}{\partial \Delta^I}(\kappa-1)\overline{n}_0 + (1-\mu)(\kappa-1)\frac{\partial \overline{n}_0}{\partial \Delta^I}$$

For $b \in \{T, I\}$

$$\frac{\partial \mu}{\partial \Delta^b} = \frac{\frac{\overline{n}_0}{\partial \Delta^b}(\overline{n}_0 + \overline{n}_{-1}) - \overline{n}_0(\frac{\overline{n}_0}{\partial \Delta^b} + \frac{\overline{n}_{-1}}{\partial \Delta^b})}{(\overline{n}_0 + \overline{n}_{-1})^2}$$

As was mentioned in Proposition 4, recall that using (3.10)-(3.13) and (3.15)-(3.16) the following holds:

$$\overline{n}_{-1} = s\overline{n}_0 \quad \text{for} \quad s \in (0,1)$$

Therefore,

$$\frac{\partial \overline{n}_{-1}}{\partial \Delta^b} = s\frac{\partial \overline{n}_0}{\partial \Delta^b} \quad \text{for} \quad s \in (0,1)$$

Using this:

$$\frac{\partial \mu}{\partial \Delta^b} = 0 \quad \text{for} \quad b \in \{T, I\}$$

Thus,

$$\frac{\partial g}{\partial \Delta^T} = (1-\mu)(\kappa-1)\frac{\partial \overline{n}_0}{\partial \Delta^T}$$

$$\frac{\partial g}{\partial \Delta^I} = (1-\mu)(\kappa-1)\frac{\partial \overline{n}_0}{\partial \Delta^I}$$

As was shown in Proposition 4, $\frac{\overline{n}_0}{\partial \Delta^T} > 0$; therefore, $\frac{\partial g}{\partial \Delta^T} > 0$. Similarly, it was established in Proposition 4 that

for the case when $1 > \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda+\psi)2\psi}{\lambda\varepsilon + \psi\upsilon} < 1 \quad \text{then} \quad \overline{n}_0 \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial \overline{n}_0}{\partial \Delta^I} < 0$$

for the case when $1 < \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda+\psi)2\psi}{(\lambda\varepsilon + \psi\upsilon)(2\lambda + 2\upsilon - 1)} < 1 \quad \text{then} \quad \overline{n}_0 \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial \overline{n}_0}{\partial \Delta^I} < 0$$

and so given $\frac{\partial g}{\partial \Delta^I} = (1-\mu)(\kappa-1)\frac{\partial \overline{n}_0}{\partial \Delta^I}$ we have that

for the case when $1 > \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda+\psi)2\psi}{\lambda\varepsilon + \psi\upsilon} < 1 \quad \text{then} \quad g \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial g}{\partial \Delta^I} < 0$$

for the case when $1 < \lambda + \psi$

$$\text{if} \quad \frac{1}{2} + \frac{1}{2}\frac{(\lambda+\psi)2\psi}{(\lambda\varepsilon + \psi\upsilon)(2\lambda + 2\upsilon - 1)} < 1 \quad \text{then} \quad g \quad \text{is} \quad \text{convex} \quad \text{in} \quad \Delta^I, \quad \text{otherwise} \quad \frac{\partial g}{\partial \Delta^I} < 0$$

Q.E.D.

Appendix V5: Proof of Proposition 6

Conditional on quality level q_i, let $V^{ij}_{1t|q_i}$, $V^{ij}_{0t|q_i}$ and $V^{ij}_{-1t|q_i}$ for $j \in \{M, D\}$ be the net present value of expected profits of being an upstream monopolist, oligopolist and an entrant respectively and supplying a downstream industry i, when a downstream industry is in state j at time t. Denote $q_i' = \kappa q_i$ for $\kappa > 1$ and note that these net present values can be written in Hamilton−Jacobi−Bellman form as follows:

$$r_t V^{iM}_{1t|q_i} - \dot{V}^{iM}_{1t|q_i} = F^M_{it|q_i} + n^M_{-1}\Bigg(\psi\Big(V^{iD}_{0t|q_i} - V^{iM}_{1t|q_i}\Big) + \Big(1-\psi\Big)\Big(V^{iM}_{0t|q_i} - V^{iM}_{1t|q_i}\Big)\Bigg) \tag{3.47}$$

$$r_t V^{iD}_{1t|q_i} - \dot{V}^{iD}_{1t|q_i} = 2F^D_{it|q_i} + n^D_{-1}\Bigg(\lambda\Big(V^{iM}_{0t|q_i} - V^{iD}_{1t|q_i}\Big) + \Big(1-\lambda\Big)\Big(V^{iD}_{0t|q_i} - V^{iD}_{1t|q_i}\Big)\Bigg) \tag{3.48}$$

$$r_t V^{iM}_{-1t|q_i} - \dot{V}^{iM}_{-1t|q_i} = 0 + n^M_{-1}\Bigg(\psi\Big(V^{iD}_{0t|q_i} - V^{iM}_{-1t|q_i}\Big) + \Big(1-\psi\Big)\Big(V^{iM}_{0t|q_i} - V^{iM}_{-1t|q_i}\Big)\Bigg) - \frac{1}{2}q_i\Big(n^M_{-1}\Big)^2 \tag{3.49}$$

$$r_t V^{iD}_{-1t|q_i} - \dot{V}^{iD}_{-1t|q_i} = 0 + n^D_{-1}\Bigg(\lambda\Big(V^{iM}_{0t|q_i} - V^{iD}_{-1t|q_i}\Big) + \Big(1-\lambda\Big)\Big(V^{iD}_{0t|q_i} - V^{iD}_{-1t|q_i}\Big)\Bigg) - \frac{1}{2}q_i n\Big(n^D_{-1}\Big)^2 \tag{3.50}$$

$$\begin{aligned} r_t V^{iM}_{0t|q_i} - \dot{V}^{iM}_{0t|q_i} = \quad & \Big(1-\Delta^T\Big)F^M_{it|q_i} + n^M_0\Bigg(\psi\Big(V^{iD}_{1t|q_i'} - V^{iM}_{0t|q_i'}\Big) + \Big(1-\psi\Big)\Big(V^{iM}_{1t|q_i'} - V^{iM}_{0t|q_i'}\Big)\Bigg) \\ & + \tilde{n}^M_0\Bigg(\psi\Big(V^{iD}_{-1t|q_i'} - V^{iM}_{0t|q_i'}\Big) + \Big(1-\psi\Big)\Big(V^{iM}_{-1t|q_i'} - V^{iM}_{0t|q_i'}\Big)\Bigg) - \tfrac{1}{2}q_i\Big(n^M_0\Big)^2 \end{aligned} \tag{3.51}$$

$$
\begin{aligned}
r_t V^{iD}_{0t|q_i} - \dot{V}^{iD}_{0t|q_i} = \; & \Big(1-\Delta^T\Big) 2F^D_{it|q_i} + n^D_0 \Bigg(\lambda \Big(V^{iM}_{1t|q'_i} - V^{iD}_{0t|q'_i} \Big) + \Big(1-\lambda\Big) \Big(V^{iD}_{1t|q'_i} - V^{iD}_{0t|q'_i} \Big) \Bigg) \\
& + \tilde{n}^D_0 \Bigg(\lambda \Big(V^{iM}_{-1t|q'_i} - V^{iD}_{0t|q'_i} \Big) + \Big(1-\lambda\Big) \Big(V^{iD}_{-1t|q'_i} - V^{iD}_{0t|q'_i} \Big) \Bigg) - \tfrac{1}{2} q_i \Big(n^D_0 \Big)^2
\end{aligned} \tag{3.52}
$$

As can be seen from the Euler equation in (3.26), in the steady state, we have that $r_t = \tilde{r}$. In addition, in steady state $\dot{V}^{iD}_{0t|q_i} = \dot{V}^{iM}_{0t|q_i} = \dot{V}^{iD}_{-1t|q_i} = \dot{V}^{iM}_{-1t|q_i} = \dot{V}^{iD}_{1t|q_i} = \dot{V}^{iM}_{1t|q_i} = 0$ and $V^{ij}_{1t|q_i} = V_1(q_i)^{ij}$, $V^{ij}_{0t|q_i} = V_0(q_i)^{ij}$ and $V^{ij}_{-1t|q_i} = V_{-1}(q_i)^{ij}$ (i.e. time subscripts are omitted) for $j \in \{M, D\}$. Moreover, as shown in Acemoglu (2009), given that the R&D costs and the profits that the upstream firms make are proportional to quality q_i, it must be the case that in steady state we have $V_z(q_i)^{ij} = V^{ij}_z q_i$ for $z \in \{0, 1\}$ and $j \in \{M, D\}$; that is, the value functions are linear in quality levels[19]. Thus, in a steady state the above-described system becomes:

$$
\tilde{r} V^{iM}_1 = \tilde{\Pi} + n^M_{-1} \Bigg(\psi \Big(V^{iD}_0 - V^{iM}_1 \Big) + \Big(1-\psi\Big) \Big(V^{iM}_0 - V^{iM}_1 \Big) \Bigg) \tag{3.53}
$$

$$
\tilde{r} V^{iD}_1 = 2 \Bigg(1-\Delta^I\Bigg) \tilde{\Pi} + n^D_{-1} \Bigg(\lambda \Big(V^{iM}_0 - V^{iD}_1 \Big) + \Big(1-\lambda\Big) \Big(V^{iD}_0 - V^{iD}_1 \Big) \Bigg) \tag{3.54}
$$

$$
\tilde{r} V^{iM}_{-1} = n^M_{-1} \Bigg(\psi \Big(V^{iD}_0 - V^{iM}_{-1} \Big) + \Big(1-\psi\Big) \Big(V^{iM}_0 - V^{iM}_{-1} \Big) \Bigg) - \frac{1}{2} (n^M_{-1})^2 \tag{3.55}
$$

$$
\tilde{r} V^{iD}_{-1} = n^D_{-1} \Bigg(\lambda \Big(V^{iM}_0 - V^{iD}_{-1} \Big) + \Big(1-\lambda\Big) \Big(V^{iD}_0 - V^{iD}_{-1} \Big) \Bigg) - \frac{1}{2} \Big(n^D_{-1} \Big)^2 \tag{3.56}
$$

$$
\begin{aligned}
\tilde{r} V^{iM}_0 = \; & \Big(1-\Delta^T\Big) \tilde{\Pi} + n^M_0 \kappa \Bigg(\psi \Big(V^{iD}_1 - V^{iM}_0 \Big) + \Big(1-\psi\Big) \Big(V^{iM}_1 - V^{iM}_0 \Big) \Bigg) \\
& + \tilde{n}^M_0 \kappa \Bigg(\psi \Big(V^{iD}_{-1} - V^{iM}_0 \Big) + \Big(1-\psi\Big) \Big(V^{iM}_{-1} - V^{iM}_0 \Big) \Bigg) - \tfrac{1}{2} \Big(n^M_0 \Big)^2
\end{aligned} \tag{3.57}
$$

19. Note that, based on this result it must be the case that $V_z(\kappa q_i)^{ij} = V^{ij}_z \kappa q_i$.

$$\begin{aligned}\tilde{r}V_0^{iD} = \;& 2\Big(1-\Delta^T\Big)\Big(1-\Delta^I\Big)\tilde{\Pi} + n_0^D\kappa\Bigg(\lambda\Big(V_1^{iM}-V_0^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_1^{iD}-V_0^{iD}\Big)\Bigg) \\ & +\tilde{n}_0^D\kappa\Bigg(\lambda\Big(V_{-1}^{iM}-V_0^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_{-1}^{iD}-V_0^{iD}\Big)\Bigg)-\tfrac{1}{2}\Big(n_0^D\Big)^2\end{aligned} \tag{3.58}$$

Take the first-order conditions in (3.55), (3.56), (3.57) and (3.58):

$$n_{-1}^M = \psi\Big(V_0^{iD}-V_{-1}^{iM}\Big)+\Big(1-\psi\Big)\Big(V_0^{iM}-V_{-1}^{iM}\Big) \tag{3.59}$$

$$n_{-1}^D = \lambda\Big(V_0^{iM}-V_{-1}^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_0^{iD}-V_{-1}^{iD}\Big) \tag{3.60}$$

$$n_0^M = \kappa\Bigg(\psi\Big(V_1^{iD}-V_0^{iM}\Big)+\Big(1-\psi\Big)\Big(V_1^{iM}-V_0^{iM}\Big)\Bigg) \tag{3.61}$$

$$n_0^D = \kappa\Bigg(\lambda\Big(V_1^{iM}-V_0^{iD}\Big)+\Big(1-\lambda\Big)\Big(V_1^{iD}-V_0^{iD}\Big)\Bigg) \tag{3.62}$$

I will be solving for the symmetric equilibrium and so the solution will imply $\tilde{n}_0^j = n_0^j$ for $j \in \{M, D\}$. Therefore, equations (3.53)−(3.62) constitute a system of 10 equations in 10 unknowns.

Q.E.D.

Appendix V6: Simplification of the system of non-linear equations that determine continuous time R&D intensities

Combine (3.59) and (3.55) to show that

$$\tilde{r}V_{-1}^{iM} = \Big(n_{-1}^M\Big)^2 - \frac{1}{2}\Big(n_{-1}^M\Big)^2$$

which implies

$$\tilde{r}V_{-1}^{iM} = \frac{1}{2}\Big(n_{-1}^{M}\Big)^2 \tag{3.63}$$

Similarly, combine (3.60) and (3.56):

$$\tilde{r}V_{-1}^{iD} = \Big(n_{-1}^{D}\Big)^2 - \frac{1}{2}\Big(n_{-1}^{D}\Big)^2$$

which implies

$$\tilde{r}V_{-1}^{iD} = \frac{1}{2}\Big(n_{-1}^{D}\Big)^2 \tag{3.64}$$

Combine (3.61) and (3.57):

$$\tilde{r}V_0^{iM} = \Bigg(1 - \Delta^T\Bigg)\tilde{\Pi} + \Big(n_0^M\Big)^2 + n_0^M\kappa\Bigg(\psi\Big(V_{-1}^{iD} - V_0^{iM}\Big) + \Big(1-\psi\Big)\Big(V_{-1}^{iM} - V_0^{iM}\Big)\Bigg) - \frac{1}{2}\Big(n_0^M\Big)^2$$

Simplifying the above expression and using (3.63) and (3.64) implies yields to:

$$V_0^{iM} = \frac{1}{\tilde{r} + n_0^M\kappa}\Bigg[\Big(1 - \Delta^T\Big)\tilde{\Pi} + \frac{1}{2}\Big(n_0^M\Big)^2 + n_0^M\kappa\Big(\frac{\psi}{2\tilde{r}}n_{-1}^D + \frac{1-\psi}{2\tilde{r}}n_{-1}^M\Big)\Bigg] \tag{3.65}$$

Combine (3.62) and (3.58):

$$\tilde{r}V_0^{im} = 2\Bigg(1 - \Delta^T\Bigg)\Bigg(1 - \Delta^I\Bigg)\tilde{\Pi} + n_{0}^{D}\Big)^2 + n_0^D\kappa\Bigg(\lambda\Big(V_{-1}^{iM} - V_0^{iD}\Big) + \Big(1-\lambda\Big)\Big(V_{-1}^{iD} - V_0^{iD}\Big)\Bigg) - \frac{1}{2}\Big(n_0^D\Big)^2$$

Similarly, simplifying the above expression and using (3.63) and (3.64) implies:

$$V_0^{iD} = \frac{1}{\tilde{r} + n_0^D\kappa}\Bigg[2\Big(1 - \Delta^T\Big)\Big(1 - \Delta^I\Big)\tilde{\Pi} + \frac{1}{2}\Big(n_0^D\Big)^2 + n_0^D\kappa\Big(\frac{\lambda}{2\tilde{r}}n_{-1}^M + \frac{1-\lambda}{2\tilde{r}}n_{-1}^D\Big)\Bigg] \tag{3.66}$$

Combine equations (3.63) and (3.59):

$$n_{-1}^M = \psi V_0^{iD} + \Big(1-\psi\Big)V_0^{iM} - V_{-1}^{iM} = \psi V_0^{iD} + \Big(1-\psi\Big)V_0^{iM} - \frac{1}{2\tilde{r}n_{-1}^M}$$

which implies

$$n_{-1}^{M}\Big(1+\frac{1}{2\tilde{r}}\Big)=\psi V_0^{iD}+\Big(1-\psi\Big)V_0^{iM} \tag{3.67}$$

Similarly, using (3.64) and (3.60) implies

$$n_{-1}^{D}\Big(1+\frac{1}{2\tilde{r}}\Big)=\lambda V_0^{iM}+\Big(1-\lambda\Big)V_0^{iD} \tag{3.68}$$

Recall (3.53):

$$\Big(\tilde{r}+n_{-1}^{M}\Big)V_1^{iM}=\tilde{\Pi}+n_{-1}^{M}\Bigg(\psi V_0^{iD}+\Big(1-\psi\Big)V_0^{iM}\Bigg)$$

Use (3.67) with the above expression:

$$V_1^{iM}=\frac{1}{\tilde{r}+n_{-1}^{M}}\Bigg[\tilde{\Pi}+\Big(n_{-1}^{M}\Big)^2\Big(1+\frac{1}{2\tilde{r}}\Big)\Bigg] \tag{3.69}$$

Similarly, combine (3.54) and (3.68):

$$V_1^{iD}=\frac{1}{\tilde{r}+n_{-1}^{D}}\Bigg[2\Big(1-\Delta^{I}\Big)\tilde{\Pi}+\Big(n_{-1}^{D}\Big)^2\Big(1+\frac{1}{2\tilde{r}}\Big)\Bigg] \tag{3.70}$$

Now, combine (3.67) with (3.65) and (3.66):

$$\begin{aligned} n_{-1}^{M}\Big(1+\tfrac{1}{2\tilde{r}}\Big) = {} & \tfrac{\psi}{r+n_0^D\kappa}\Bigg[2\Big(1-\Delta^{T}\Big)\Big(1-\Delta^{I}\Big)\tilde{\Pi}+\tfrac{1}{2}\Big(n_0^D\Big)^2+n_0^D\kappa\Big(\tfrac{\lambda}{2\tilde{r}}n_{-1}^{M}+\tfrac{1-\lambda}{2\tilde{r}}n_{-1}^{D}\Big)\Bigg] \\ & +\tfrac{1-\psi}{r+n_0^M\kappa}\Bigg[\Big(1-\Delta^{T}\Big)\tilde{\Pi}+\tfrac{1}{2}\Big(n_0^M\Big)^2+n_0^M\kappa\Big(\tfrac{\psi}{2\tilde{r}}n_{-1}^{D}+\tfrac{1-\psi}{2\tilde{r}}n_{-1}^{M}\Big)\Bigg] \end{aligned} \tag{3.71}$$

Similarly, combine (3.68) with (3.65) and (3.66):

$$\begin{aligned} n_{-1}^{D}\Big(1+\tfrac{1}{2\tilde{r}}\Big) = {} & \tfrac{\lambda}{r+n_0^M\kappa}\Bigg[\Big(1-\Delta^{T}\Big)\tilde{\Pi}+\tfrac{1}{2}\Big(n_0^M\Big)^2+n_0^M\kappa\Big(\tfrac{\psi}{2\tilde{r}}n_{-1}^{D}+\tfrac{1-\psi}{2\tilde{r}}n_{-1}^{M}\Big)\Bigg] \\ & +\tfrac{1-\lambda}{r+n_0^D\kappa}\Bigg[2\Big(1-\Delta^{T}\Big)\Big(1-\Delta^{I}\Big)\tilde{\Pi}+\tfrac{1}{2}\Big(n_0^D\Big)^2+n_0^D\kappa\Big(\tfrac{\lambda}{2\tilde{r}}n_{-1}^{M}+\tfrac{1-\lambda}{2\tilde{r}}n_{-1}^{D}\Big)\Bigg] \end{aligned} \tag{3.72}$$

Combine (3.57) with (3.65), (3.69) and (3.70):

$$n_0^M = \kappa\Bigg\{\psi\Big(\tfrac{1}{\tilde{r}+n_{-1}^D}\Big[2\big(1-\Delta^I\big)\tilde{\Pi}+\big(n_{-1}^D\big)^2\big(1+\tfrac{1}{2\tilde{r}}\big)\Big]+\Big(1-\psi\Big)\Big(\tfrac{1}{\tilde{r}+n_{-1}^M}\Big[\tilde{\Pi}+\big(n_{-1}^M\big)^2\big(1+\tfrac{1}{2\tilde{r}}\big)\Big]\Big)$$
$$-\tfrac{1}{\tilde{r}+n_0^M\kappa}\Big[\big(1-\Delta^T\big)\tilde{\Pi}+\tfrac{1}{2}\big(n_0^M\big)^2+n_0^M\kappa\big(\tfrac{\psi}{2\tilde{r}}n_{-1}^D+\tfrac{1-\psi}{2\tilde{r}}n_{-1}^M\big)\Big]\Bigg\} \tag{3.73}$$

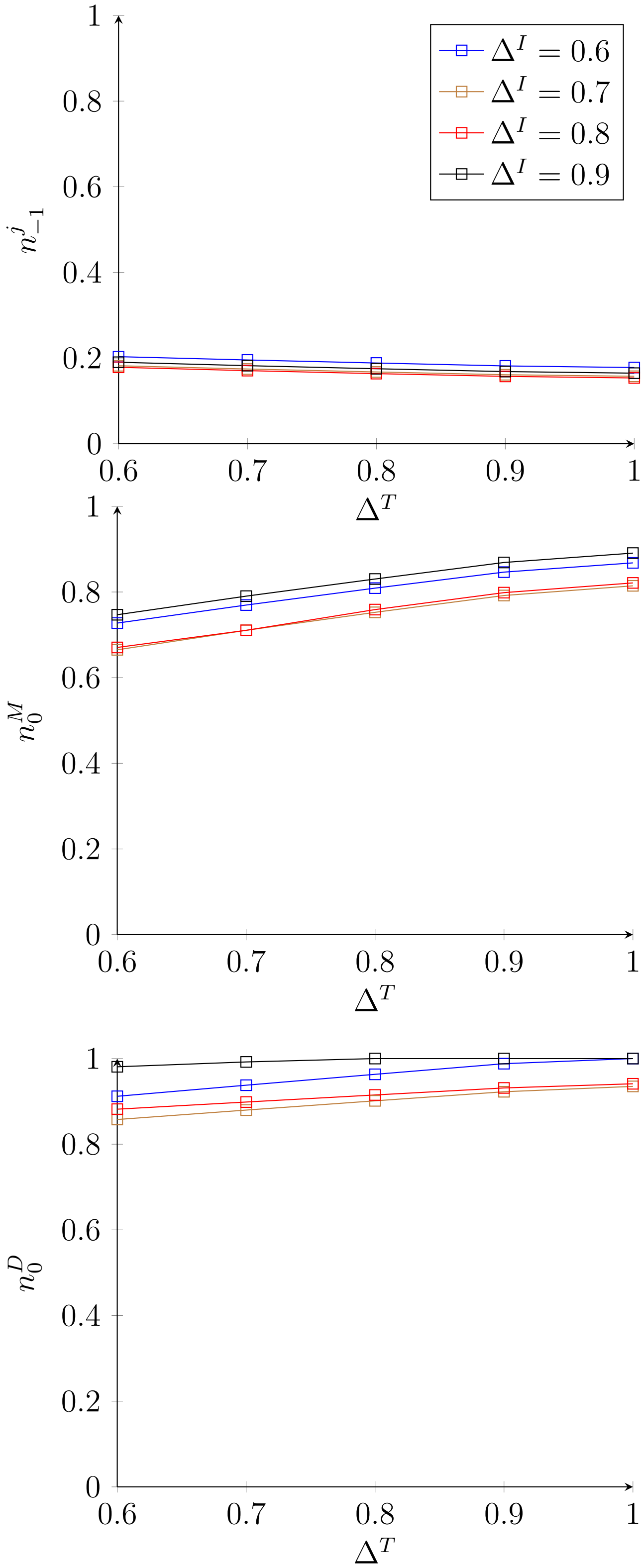
Finally, combining (3.58) with (3.66), (3.69) and (3.70) implies:

$$n_0^D = \kappa\Bigg\{\lambda\Big(\tfrac{1}{\tilde{r}+n_{-1}^M}\Big[\tilde{\Pi}+\big(n_{-1}^M\big)^2\big(1+\tfrac{1}{2\tilde{r}}\big)\Big]\Big)+\Big(1-\lambda\Big)\Big(\tfrac{1}{\tilde{r}+n_{-1}^D}\Big[2\big(1-\Delta^I\big)\tilde{\Pi}+\big(n_{-1}^D\big)^2\big(1+\tfrac{1}{2\tilde{r}}\big)\Big]\Big)$$
$$-\tfrac{1}{\tilde{r}+n_0^D\kappa}\Big[2\big(1-\Delta^T\big)\big(1-\Delta^I\big)\tilde{\Pi}+\tfrac{1}{2}\big(n_0^D\big)^2+n_0^D\kappa\big(\tfrac{\lambda}{2\tilde{r}}n_{-1}^M+\tfrac{1-\lambda}{2\tilde{r}}n_{-1}^D\big)\Big]\Bigg\} \tag{3.74}$$

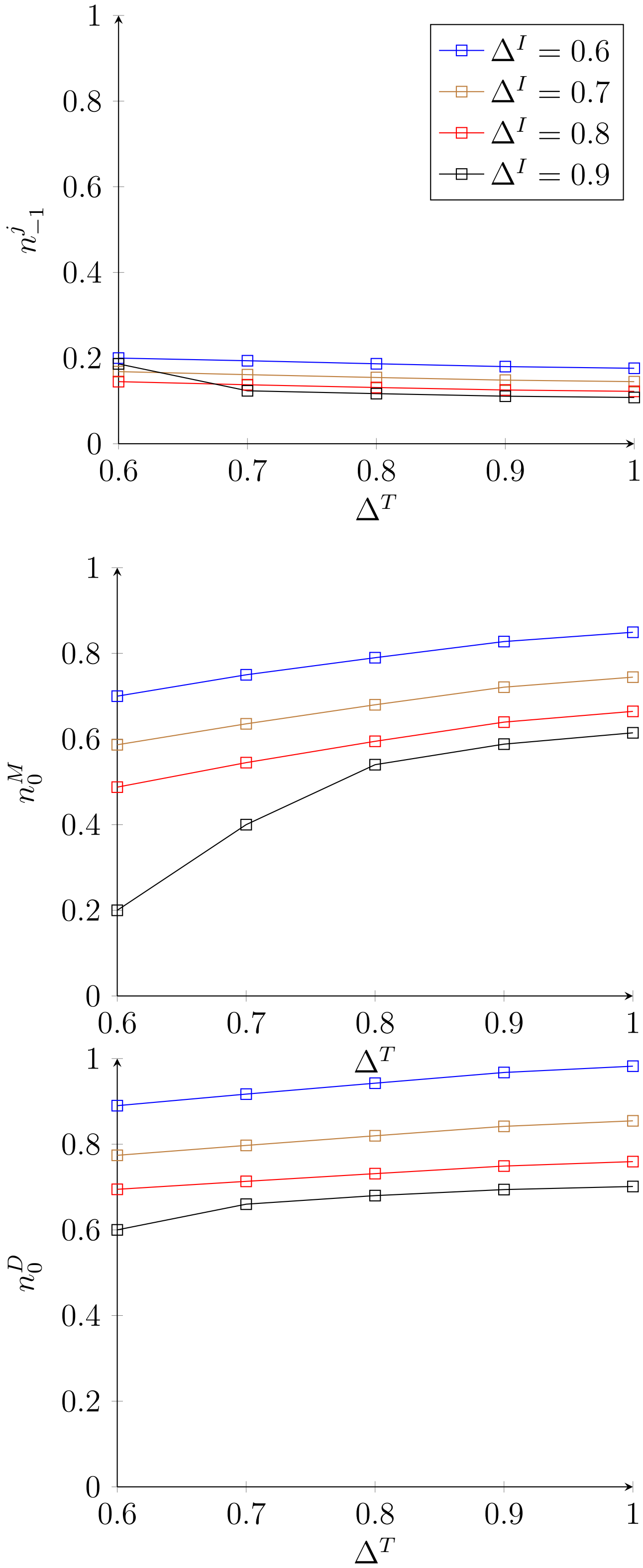
Equations (3.71)-(3.74) constitute a system of four non-linear equations in four unknowns, which are $n_{-1}^M, n_{-1}^D, n_0^M$ and n_0^D. These are the equations, which I numerically solve for given values of parameters and simulate the results.

Appendix V7: Effect of Δ^T on R&D intensities in continuous time model

With both downstream firm entry and exit probabilities being responsive to the changes in downstream competition levels ($\frac{3\overline{\psi}}{2} < \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} < \upsilon$):

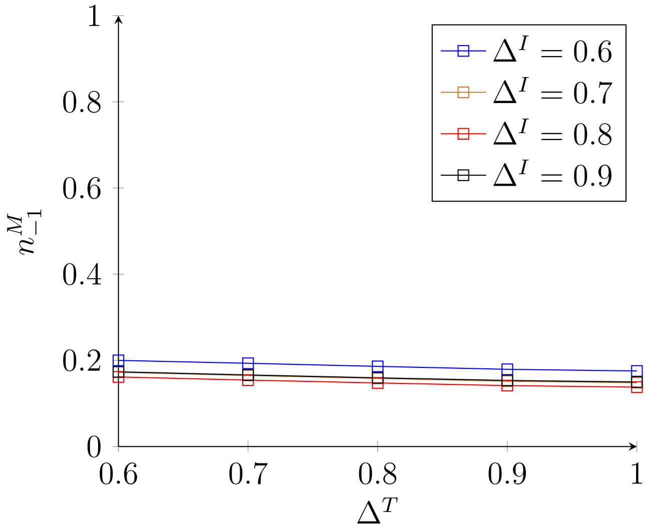


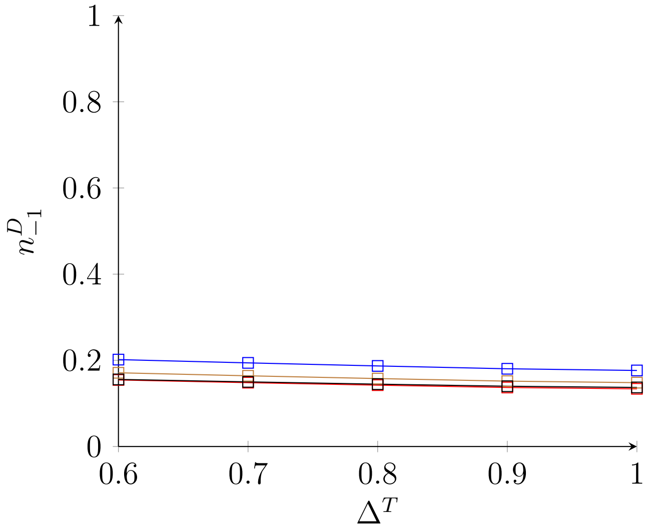
With both downstream firm entry and exit probabilities being unresponsive to the changes in downstream competition levels ($\frac{3\overline{\psi}}{2} \geq \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$):

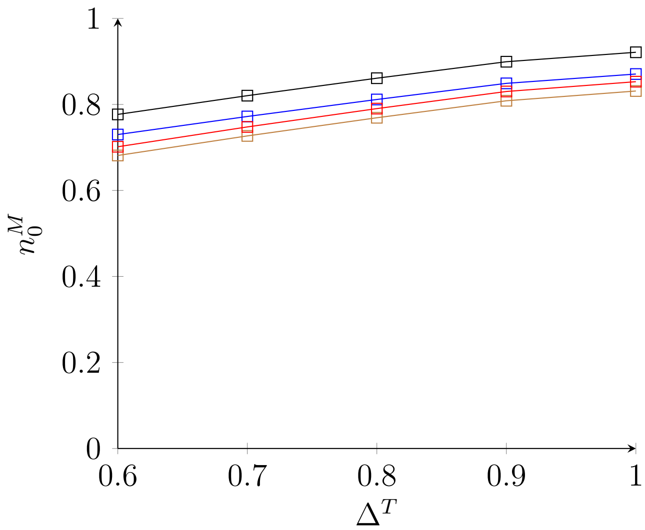


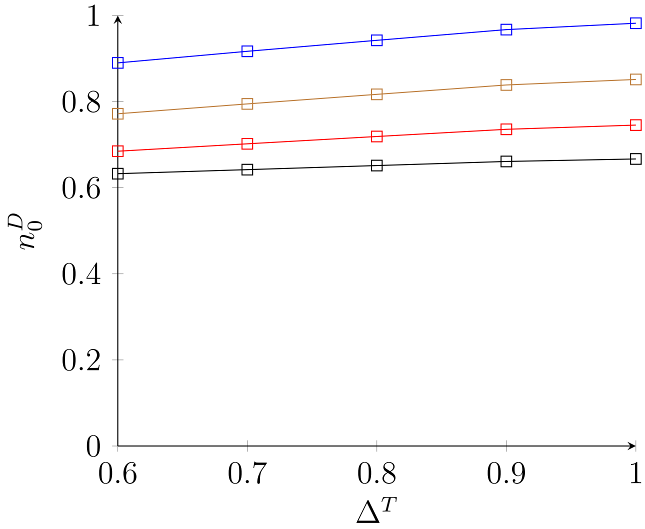
With the downstream firm entry probability being responsive and the exit probability being unresponsive to the changes in downstream competition levels ($\frac{3\overline{\psi}}{2} < \varepsilon$ and

$\frac{3(1-\bar{\lambda})}{2} \geq \upsilon$):



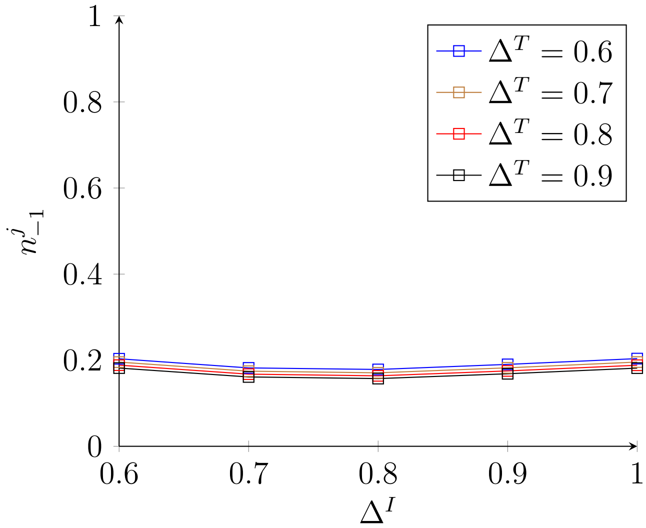


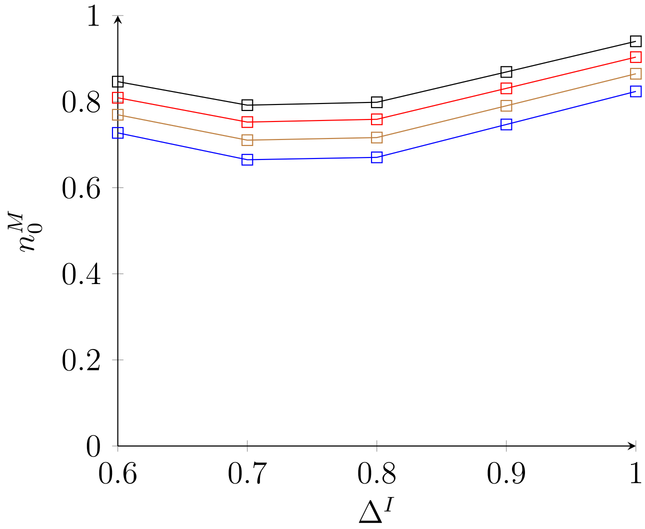


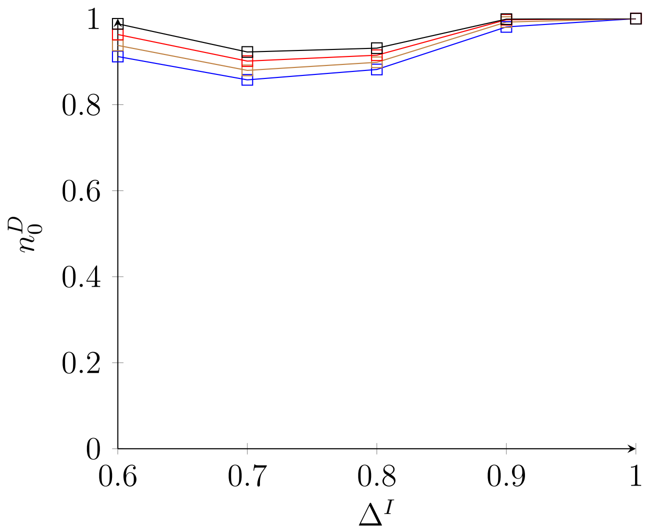


Appendix V8: Effect of Δ^I on R&D intensities in continuous time model

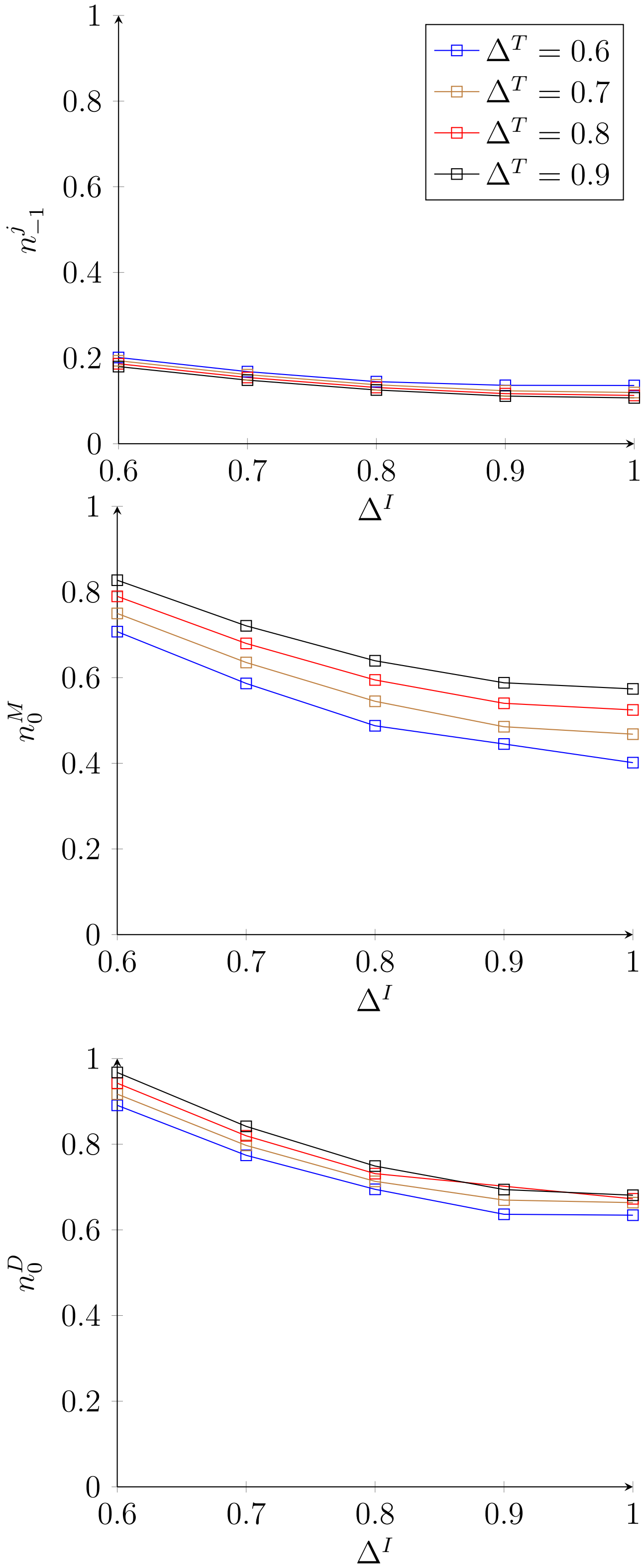
With both downstream firm entry and exit probabilities being responsive to the changes in downstream competition levels ($\frac{3\overline{\psi}}{2} < \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} < \upsilon$):





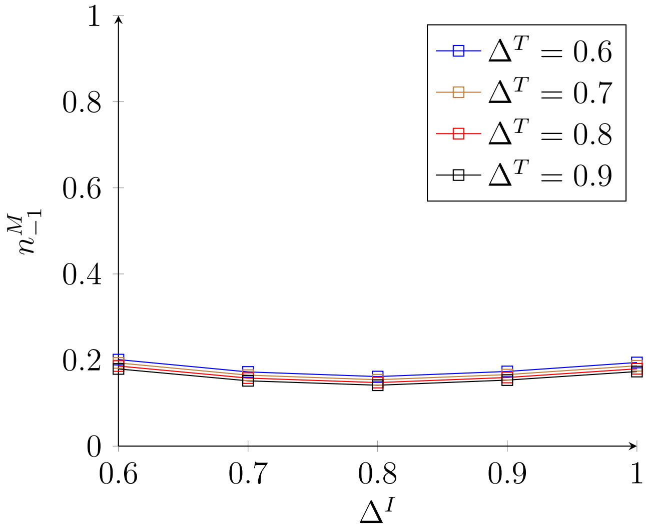


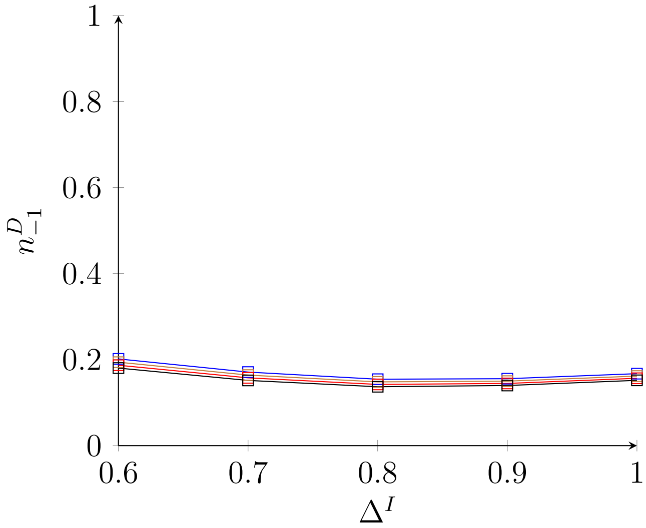
With both downstream firm entry and exit probabilities being unresponsive to the changes in downstream competition levels ($\frac{3\overline{\psi}}{2} \geq \varepsilon$ and $\frac{3(1-\overline{\lambda})}{2} \geq \upsilon$):

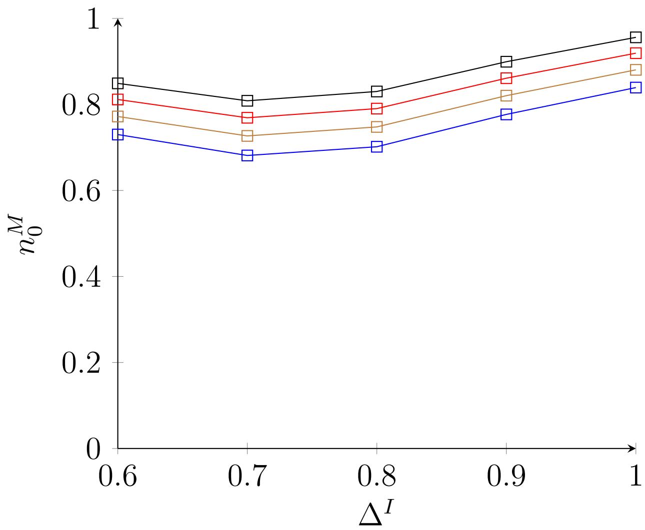


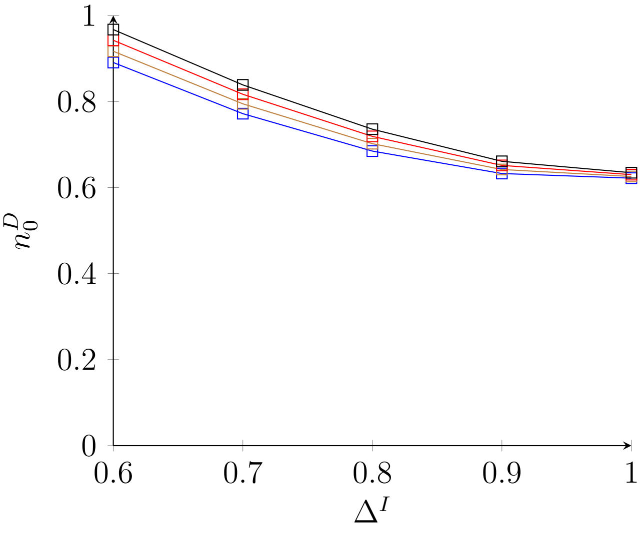
With the downstream firm entry probability being responsive and the exit probability being unresponsive to the changes in downstream competition levels ($\frac{3\overline{\psi}}{2} < \varepsilon$ and

$\frac{3(1-\bar{\lambda})}{2} \geq \upsilon$):








1
0.8
0.6
0.4
0.2
0
n_0^D
0.6
0.7
0.8
0.9
1
Δ^I

Conclusion

This thesis analyzed the interplay between innovation, productivity and market dynamics in three chapters.

In the first chapter, I explored the relationship between firms' workforce skill sets and markups. Using the German-matched employee-employer dataset, I estimated markups using the production approach. The markup estimates suggest that an average German firm charges a price that is 50% higher than its marginal cost, which is similar to the findings from the US. I also reported that the average German markups exhibit a slight declining trend over time.

I recovered the worker-productivity parameters using the AKM two-way fixed effects approach. The results indicate that there is a positive sorting in the German labour market. Furthermore, the relationship between worker productivity parameters and firm markups is found to have an inverted U shape.

To explain the latter finding, I developed a theoretical model which suggests that firms' incentives to enter the market and asymmetric information on the consumers' side can explain the empirical relationship. In the model, I showed that the incentives of entrants to enter the market depend on two counteracting effects: a positive demand effect and a negative cost effect. The analysis showed that if the cost of entry is concave, there is a cutoff point in worker productivity, below which the cost effect dominates the demand effect, pushing down entry into sectors and so increasing markups. However, above that cutoff point, the demand effect starts to dominate, which implies that entrants find it increasingly profitable to enter and benefit from high demand. This, in turn, pushes up entry and so reduces markups, deriving the inverted-U relationship.

In the second chapter, I analyzed whether corruption levels in the firms' countries of origin matter for the impact of an export demand shock on firms' R&D investments. The theoretical model suggested that firms originating from non-corrupt states should be more productive than the ones from corrupt countries. Furthermore, the model discussed that an export demand shock has two opposite effects on firms' innovations: a positive market size effect and a negative competition effect. The equilibrium of the model suggested that the market size effect is stronger and the competition effect is weaker for firms originating from non-corrupt states. Therefore, if the market size effect is larger than the competition effect for all firms, the exporters from non-corrupt countries should be willing to increase their innovation investments more than the firms from corrupt states. However, if the competition effect is larger than the market size effect for all exporters, an increase in export market size will hurt firms from non-corrupt states less. It could also be possible the R&D investments of firms from corrupt countries decline/stay the same, but the investments of the ones from non-corrupt states go up, but not the opposite.

I tested these predictions empirically. I constructed a measure of the corruption of a country, using data on countries' rankings from three different non-governmental organisations. Further, I used aggregate export data from the United Nations' Comtrade and firm-level microdata from Worldscope, which covers firms from more than 120 countries. I found a statistically significant association between export demand shocks and R&D investments of firms from non-corrupt states in most of the empirical specifications. However, the empirical results indicated that there is no statistically significant association between export demand shocks and R&D investments of firms from corrupt countries.

Finally, in the third chapter, using a theoretical model, I analyzed how competition affects firms' innovation incentives in vertically related markets. I considered vertically related industries, where upstream innovating firms supply products to downstream non-innovating ones. I showed that increased competition among innovating firms positively affects firms' incentives to invest in R&D. However, I showed that in upstream industries occupied by an incumbent monopolist that faces an entrant, higher (post-entry) competition levels hurt firms' innovation incentives.

The analysis in the chapter showed that competition among non-innovating sectors affects the innovators' R&D incentives non-monotonically. More precisely, it was shown that the relation between the non-innovating sector's competition and the innovator's R&D incentives is either U-shaped or decreasing. The simulations of the continuous time version of the model supported the predictions of the benchmark model as well.