Summer 2019

Essays on production and investment

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ESSAYS ON PRODUCTION AND INVESTMENT

by

Huizhong Liu

A thesis submitted in partial fulfillment of the
requirements for the Doctor of Philosophy
degree in Economics
in the Graduate College of
The University of Iowa

August 2019

Thesis Supervisor: Professor Anne P. Villamil

ACKNOWLEDGEMENTS

First and foremost I would like to thank my advisor Anne P. Villamil, for encouraging my research and for allowing me to grow as an economist. Her guidance and endless support made the completion of my dissertation possible. I would also like to thank Rabah Amir for his crucial remarks that shaped my final dissertation. His advice on both research as well as on my career have been invaluable. Next, I would like to thank the rest of my dissertation committee members Nicholas C. Yannelis, Suyong Song and Luciano de Castro for their time and insightful questions. I am incredibly grateful to my parents and friends. This dissertation would not have been possible without their love, patience, and encouragement.

ABSTRACT

This dissertation contributes to the understanding of production and investment decisions under different circumstances. Specifically, it focuses on two aspects: (1) in a market with financial frictions, how entrepreneurs choose their production sectors and finance their business; (2) in a market with spillovers in research and development (R&D), how spillover effect influences firms' R&D investment and other market performances.

In Chapter 1, I examine how financial frictions affect occupational shifts and structural transformations between the service sector and the manufacturing sector. I construct a general equilibrium occupational choice model with intermediation costs and contract enforcement, in which agents can choose to be entrepreneurs in the service or manufacturing sector, or to be workers. The model is calibrated to match Chinese statistics and is used to conduct policy experiments that vary intermediation and enforcement costs. I find that high intermediation costs cause the contribution to output and the number of workers employed in the service sector to increase. They also decrease output per capita in the service sector. The service sector size and enforcement do not have a monotonic relationship; the association is positive when enforcement cost is sufficiently high and it is negative when enforcement cost is sufficiently low. Counterfactual experiments are performed for the U.S., Brazil and the Philippines. I find that intermediation costs and enforcement can explain almost half of the sector size gap with Brazil and the Philippines.

In Chapter 2, we consider a one-stage Cournot duopoly of R&D. We characterize the Nash equilibrium of the one-stage game and provide a comparison with the two-stage version of the same Cournot model of R&D/product market competition. We look at R&D expenditures, profits, output, and welfare. Under perfect symmetry, the one-stage model always leads to higher profits when the spillover parameter is not equal to $1/2$. Moreover, the one-stage model implies more R&D expenditure and higher welfare if and only if the spillover parameter is greater than $1/2$.

In Chapter 3, we consider a one-stage Cournot duopoly with R&D and spillovers in R&D inputs and makes a comparison with the two-stage game version where R&D levels are observed before the output choices. We focus on the possibility of a prisoner's dilemma in R&D. By adding an initial period to our one-stage model, wherein firms decide whether or not to conduct R&D, we find that there is no prisoner's dilemma in R&D regardless of the level of spillover effects.

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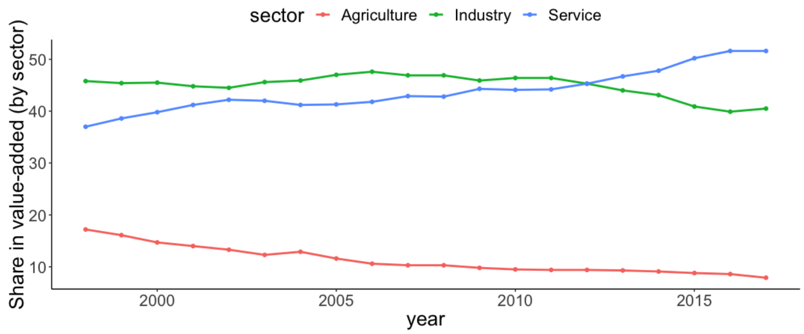
1. THE IMPACT OF FINANCIAL FRICTIONS ON STRUCTURAL TRANSFORMATION IN CHINA

1.1. Introduction

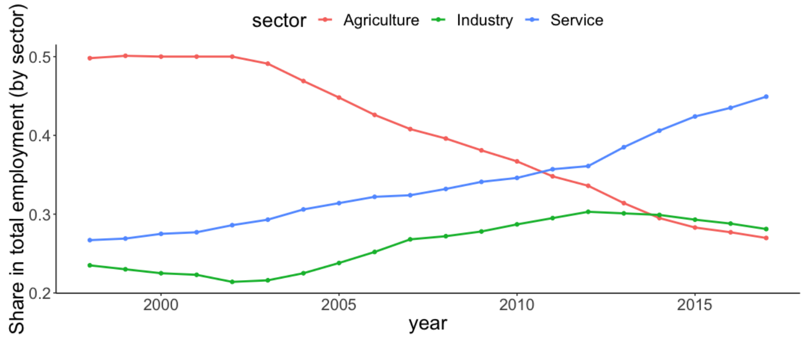
The size of the service sector as a fraction of GDP varies with a country's development. Low-income countries may experience a decline in the service size relative to industry as they reach a middle-income level. Later, with further growth, services once again dominate in a high-income economy. Given the large difference in financial development across countries, there is a large literature on financial frictions and economic development (Levine (1999), Antonio Antunes, Cavalcanti, and Villamil (2008),Townsend and Ueda (2010)). However, the literature featuring the impacts of financial frictions on structural transformation is sparse.

Xiu-hua and Ying (2006) use empirical methods to show that the transformation efficiency of savings-to-loans facilitates structural change from agriculture to non-agriculture in China. Together with increasing external financing [1], China has successfully transformed from an agriculture-based economy to a manufacturing-based economy. Now China is in the second phase of structural transformation, shifting from manufacturing to services (See Figure 1.1. How will financial markets affect the second phase transformation? Will they continue to play a vital role in the structural transformation as before? My goal in this pa-

[1] Domestic credit to the private sector as a percentage of GDP almost triples for the period 1980-2017.



(a) Sector output share



(b) Sector employment share

Figure 1.1: Sector share(Source: NBS of China)

per is to capture and quantify the effects of financial frictions on sector size, sector employment, output per capita, firm size and occupational choice.

I build a general equilibrium occupational choice model with financial frictions that incorporate two sectors in entrepreneurship: services and manufacturing[2]. The two sectors differ in factor shares and span of control (Lucas Jr (1978)). These differences lead to different scales of enterprises (i.e., firm sizes) in the two

[2]Manufacturing includes all non-services and non-agriculture industries. See the Appendix for details.

sectors[3]. Individuals can choose whether to be entrepreneurs in either sector or to be a wage worker. They are endowed with heterogeneous ability and bequest. The ability to manage a firm is drawn from a fixed distribution and is independent within and across generations. The bequests distribution evolves endogenously as agents choose consumption and bequests to maximize their utility, subject to lifetime wealth. There are two types of financial frictions: intermediation costs, defined as deadweight costs of intermediating loans, and limited contract enforcement to ensure loan repayment. An agent's type (ability and bequest) and credit market imperfections endogenously determine the occupational choice and firm size.

The variation of intermediation costs and enforcement have two opposite effects: a demand effect and general equilibrium effect. As for the demand effect, either weaker contract enforcement or higher intermediation costs decrease entrepreneurs' demand for loans for a given interest rate, which implies less capital and thus firm size shrinks. To clear the labor market, more but less productive entrepreneurs enter. Conversely, less borrowing drives down interest rates. Entrepreneurs can be funded at a lower cost, which increases productivity and firm size. This is the general equilibrium effect.

The two effects also generate different occupational shifts between the manufacturing sector and the service sector. Entrepreneurs in the manufacturing sector tend to run larger firms due to a greater span of control and thus have

[3]Buera and Kaboski (2012a) suggests that manufacturing has a larger scale of establishment relative to services and such differences in production scale generate structural change between manufacturing and services.

more financing needs, which makes the manufacturing sector more vulnerable to borrowing constraints. Therefore, the demand effect causes entrepreneurs to shift from the manufacturing sector to the service sector due to a tightened borrowing constraint. The general equilibrium effect reverses the shift due to lower borrowing costs. The aggregate effect of financial frictions on, for instance, output per capita, is unclear.

To quantify the sector change with varying intermediation costs and enforcement, I calibrate the model to match key statistics of the Chinese economy. I find that intermediation costs and enforcement have an almost equal effect on the size of the service sector, the number of workers employed in the service sector and output per capita, both for the service sector and for the whole economy. A rise in enforcement level boosts output per capita, but enforcement and the service sector size do not have a monotonic relationship. The association is positive when the enforcement level is sufficiently high and it is negative when the enforcement level is sufficiently low. This implies a hump-shape development pattern of the manufacturing sector[4].

Next, I use independent estimates of intermediation costs and contract enforcement in Brazil, the U.S. and the Philippines to compare the model's predictions with the data observed in these three countries. The results suggest that intermediation costs and enforcement can account for about 65% of the differences in the service sector size between China and Brazil. However, I do not find that

[4]Duarte and Restuccia (2010) proposes that the sectoral differences in labor productivity generate such a hump-shape structural transformation. Buera and Kaboski (2012a) suggests an alternative based on different scale production units across sectors.

differences in intermediation costs and enforcement can account for much of the difference in output per capita across all four countries. Finally, non-financially constrained firms are added (i.e. a state-owned sector) to check the robustness of the results and explore the effect of financial frictions on total factor productivity (TFP).

My work adds to literature that studies resource reallocation across broadly defined sectors. Existing literature presents two channels that drive such reallocation. The first channel is driven by preferences. It links structural change to demand. Buera and Kaboski (2012b) argue that the movement of consumption into more skill-intensive output increases the share of the market services sector relative to home production. Kongsamut, Rebelo, and Xie (2001) consider differences in the income elasticity of demand across goods. These differences would shift demand as capital accumulates and income rises. Therefore resources are reallocated from goods with low demand elasticity to goods with high demand elasticity. The second channel is driven by technological differences across sectors. Ngai and Pissarides (2007) focus on differences in sectoral-level TFP growth. Acemoglu and Guerrieri (2008) examine sectoral differences in the elasticity of output with respect to capital. And Alvarez-Cuadrado, Van Long, and Poschke (2017) put forward an alternative based on sectoral differences in the elasticity of substitution between capital and labor to explain changes in the sectoral composition of output. Both channels generate structural change as sector-level TFP diverges or capital accumulates. I explicitly model one source that affects capital accumulation (financial frictions).

This work is closely related to two other papers. Antonio Antunes, Cavalcanti, and Villamil (2008) create an occupational choice model to show that the differences across countries in intermediation costs and enforcement generate differences in credit, income inequality, occupational choice and output. I extend their model by incorporating multiple sectors to explore the structural change. Buera, Kaboski, and Shin (2011) use a two sector model, starting from a perfect enforcement state, to quantify the impact of enforcement on sector-level TFP and establishment size differences. They model the service sector and the manufacturing sector, which differ in the per period fixed costs, to generate different financing needs. Instead, I use different span of control and factor intensity to differentiate the two sectors. My focus is on how the enforcement and intermediation costs affect sector size as a fraction of output and occupational shifts.

The paper is organized as follows: section 1.2 constructs the model. Section 1.3 describes entrepreneurs' behavior, occupational choice sets and competitive equilibrium. Section 1.4 presents calibration results. Section 1.5 concludes.

1.2. The model

I consider an economy with a continuum of measure one agents who live for one period. At the end of each period, each agent reproduces another such that the population is constant. There is one good that can be used for consumption or investment, or left to the next generation as bequest. There are two production sectors: the service sector and the manufacturing sector. Agents can choose to be workers or entrepreneurs in either sector. Time is discrete with $t = 0,1,2,...$.

Preferences In period t, agent $i's$ utility is determined by personal consumption and a bequest to offspring, denoted by c_t^i, and b_{t+1}^i, respectively. The utility function has the form

$$U^i = (c_t^i)^\gamma (b_{t+1}^i)^{1-\gamma}, \gamma \in (0,1) \tag{1}$$

The utility function implies that agents are risk-neutral with respect to income since the indirect utility function is linear in wealth.

Endowment Agents are endowed with initial wealth and managerial ability. The bequest of agent i at time t is denoted by b_t^i, and is inherited from the previous generation. Managerial ability x^i is drawn from a continuous cumulative distribution function $\Gamma(x)$, with $x \in [\underline{x}, \overline{x}]$, and is independently and identically distributed across generations. Thus, in each period agents are distinguished by (b_t^i, x_t^i).

Production sectors There are two production sectors: the service sector (S), which is less capital intensive and subject to a smaller span of control, and the manufacturing sector (M), which is more capital intensive and subject to a larger span of control. Entrepreneurs with ability x operate a technology that uses labor n and capital k to produce a single consumption good, y. The production function in the manufacturing sector is

$$y = xk^{\alpha_M} n^{\beta_M} \tag{2}$$

The production function in the service sector is

$$y = xk^{\alpha_S} n^{\beta_S} \tag{3}$$

where $\alpha_j, \beta_j > 0$, $j = S, M$. $\alpha_S + \beta_S < \alpha_M + \beta_M < 1$, and $0 < \alpha_S < \alpha_M < 1$.

Capital fully depreciates between periods.

Capital market There are two financial frictions.

- τ: Agents can rent their capital b to a financial intermediary and earn interest rate r. They can also borrow from the intermediary to start a business. The part of the loan that is fully collateralized by b costs r, and the remainder costs $r + \tau$, where τ is intermediation costs.

- ϕ: Borrowers cannot commit *ex ante* to repay. Agents who default on their debt have to pay a penalty equal to percentage ϕ of profit.

1.3. Optimal behavior

1.3.1. Entrepreneurs

Let $j = S, M$ index two production sectors. Agents who have sufficient initial wealth and managerial ability to become entrepreneurs choose the amount of capital and the number of employees to maximize their profit subject to some constraints. First, consider the problem of entrepreneurs operating in sector j for a given level of capital k and wages w.

$$\pi_j(k,x;w) = \max_{n_j} \quad xk^{\alpha_j} n^{\beta_j} - wn_j \tag{4}$$

This gives the labor demand

$$n_j(k,x;w) = \left(\frac{\beta_j x k^{\alpha_j}}{w}\right)^{1/(1-\beta_j)} \tag{5}$$

Substituting (5) into (4) yields the profit function for a given level of k,

$$\pi_j(k,x;w) = [(1-\beta_j)(xk^{\alpha_j})]^{1/(1-\beta_j)} \left(\frac{\beta_j}{w}\right)^{\beta_j/(1-\beta_j)} \tag{6}$$

Second, let a be the amount of self-finance and l be the amount of funds borrowed from a financial intermediary. Entrepreneurs choose an optimal amount of capital through a and l to maximize profit. They may be credit constrained or unconstrained. Each case is considered.

Unconstrained problem When initial wealth is sufficient to finance their business (i.e. $b > a$ and $l = 0$) without borrowing, entrepreneurs solve

$$\max_{k_j \geq 0} \quad \pi_j(k_j,x,w) - (1+r)k_j \tag{7}$$

This gives the optimal physical capital

$$k_j^*(x;w,r) = \left[\frac{x}{(\frac{w}{\beta_j})^{\beta_j}(\frac{1+r}{\alpha_j})^{1-\beta_j}}\right]^{\frac{1}{1-\alpha_j-\beta_j}} \tag{8}$$

Constrained problem When initial wealth may not be sufficient to finance their business (i.e. $b \geq a_j$ and $l_j \geq 0$) , entrepreneurs solve

$$V_j(b,x;w,r) = \max_{l_j \geq 0, a_j \geq 0} \quad \pi_j(a_j + l_j, x, w) - (1+r)a - (1+r+\tau)l_j \tag{9}$$

subject to:

$$a_j \leq b, \tag{10}$$

$$\phi \pi(a_j + l_j, x; w) \geq (1+r+\tau)l_j. \tag{11}$$

The constrained problem yields the optimal policy function $a_j(b,x;w,r)$ and $l_j(b,x;w,r)$ that define the capital employed by each firm,

$$k_j(b,x;w,r) = a_j(b,x;w,r) + l_j(b,x;w,r) \tag{12}$$

The Lagrangian is

$$L_j = \pi_j(a_j + l_j, x; w) - (1+r)a_j - (1+r+\tau)l_j + \lambda_j[\phi \pi_j(a_j + l_j, x; w) - (1+r+\tau)l_j] + \chi_j(b - a_j)$$

The Kuhn-Tucker conditions are:

$$\frac{\partial L_j}{\partial l_j} = \pi_1^j(a_j + l_j, x; w) - (1+r+\tau) + \lambda_j(\phi \pi_1^j(a_j + l_j, x; w) - (1+r+\tau)) \leq 0 \tag{13}$$

$$\frac{\partial L_j}{\partial a_j} = \pi_1^j(a_j + l_j, x; w) - (1+r) + \lambda_j \phi \pi_1^j(a_j + l_j, x; w) - \chi_j \leq 0 \tag{14}$$

$$\lambda_j(\phi \pi_j(a_j + l_j, x; w) - (1 + r + \tau) l_j) = 0 \tag{15}$$

$$\chi_j(b - a_j) = 0 \tag{16}$$

$$l_j \geq 0, \quad \frac{\partial L_j}{\partial l_j} l_j = 0, \quad a_j \geq 0, \quad \frac{\partial L_j}{\partial a_j} a_j = 0, \quad \lambda_j \geq 0\,, \quad \chi_j \geq 0$$

There are four cases for the Kuhn-Tucker conditions:

1. $0 < a_j < b$, and $l_j = 0$. Then from (14) and(15), $\chi_j = \lambda_j = 0$ and

$$a_j = k_j^*(x; r, w) \tag{17}$$

2. $0 < a_j = b$, and $l_j = 0$. Then we have $\lambda_j = 0$ and χ_j is given by (13) at equality

$$\chi_j = \pi_1^j(a_j + l_j, x; w) - (1+r) \tag{18}$$

3. $0 < a_j = b$, and $l_j > 0$, but $\phi \pi_j(a_j + l_j, x; w) - (1 + r + \tau) l_j > 0$. Then from (14), $\lambda_j = 0$, and by (12) and (13) at equality, it follows that $\chi_j = \tau$.

$l_j^* = k_j^*(x; r+\tau, w) - b$, where

$$k_j^*(x;w,r) = \left[\frac{x}{(\frac{w}{\beta_j})^{\beta_j} (\frac{1+r+\tau}{\alpha_j})^{1-\beta_j}} \right]^{\frac{1}{1-\alpha_j-\beta_j}}$$

4. $0 < a_j = b$, and $l_j > 0$, but $\phi\pi_j(a_j + l_j, x; w) - (1+r+\tau)l_j = 0$, $\chi_j = \tau(1+\lambda_j)$.

1.3.2. Occupational choice

Occupational choice determines lifetime income. An agent will choose the occupation that gives him the greatest income. Define $\Omega = [0,\infty] \times [\underline{x}, \bar{x}]$. And define the sets $E(w,r), E^c(w,r), E_M(w,r), E_S(w,r)$ as follows:

$$E(w,r) = \{(b,x) \in \Omega : max\{V_M(b,x;w,r), V_S(b,x;w,r)\} \geq w\} \tag{19}$$

$$E^c(w,r) = \{(b,x) \in \Omega : w \geq max\{V_M(b,x;w,r), V_S(b,x;w,r)\}\} \tag{20}$$

$$E_M(w,r) = \{(b,x) \in E(w,r) : V_M(b,x;w,r) \geq V_S(b,x;w,r)\} \tag{21}$$

$$E_S(w,r) = \{(b,x) \in E(w,r) : V_S(b,x;w,r) \geq V_M(b,x;w,r)\} \tag{22}$$

For any $w,r > 0$, $E^c(w,r)$ is the set for which an agent chooses to be a worker. $E_M(w,r)$ is the set for which an agent chooses to be an entrepreneur in the manufacturing sector. $E_S(w,r)$ is the set for which an agent chooses to be an

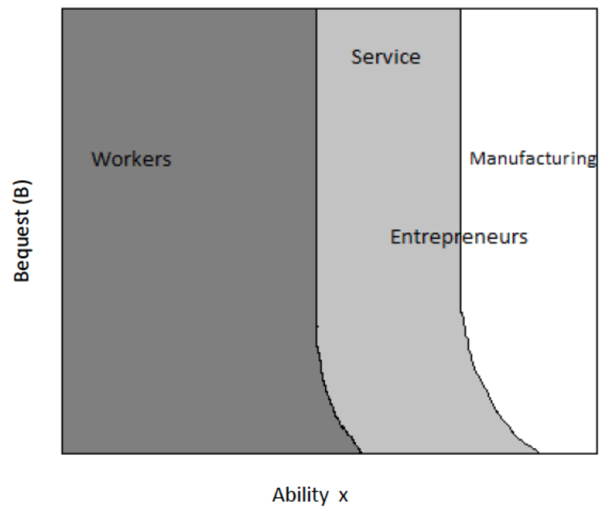


Figure 1.2: Occupational choice

entrepreneur in the service sector.

Lemma 1.1 Define $b_e(x;w,r)$ as the curve in set Ω such that $max\{V_M(b,x;w,r), V_S(b,x;w,r)\} = w$. Then there exists an $x^*(w,r)$ such that $\frac{\partial b_e(x;w,r)}{\partial x} < 0$ for $x > x^*(w,r)$ and $\frac{\partial b_e(x;w,r)}{\partial x} = -\infty$ for $x = x^*(w,r)$. And for all $x > x^*(w,r)$,

1. If $b < b_e(x;w,r)$, then $(b,x) \in E^c(w,r)$.

2. If $b \geq b_e(x;w,r)$, then $(b,x) \in E(w,r)$.

Proof. See António Antunes, Cavalcanti, and Villamil (2008) □

Figure 1.2 shows one possible occupational choice in (b,x) space. It suggests that agents with a very low bequest choose to be workers when their managerial ability is low, i.e, $x < x^*$. For $x > x^*$, agents may become entrepreneurs depending on if they are credit constrained. When initial bequest is low, agents choose to be workers, even though their managerial ability is higher than x^*. The negative association between $b_e(x)$ and x implies agents with higher ability need less initial wealth to run a firm. Firms in the manufacturing sector tend to have larger scale and thus are more vulnerable to financial frictions. Given initial wealth, constrained entrepreneurs will operate in the manufacturing sector only if they have high managerial ability so that they can overcome borrowing costs. The relationship between initial wealth and operating in the manufacturing sector is ambiguous. On one hand, given an additional amount of wealth, if both inputs (labor and capital) are increased by the same proportion, the manufacturing sector would generate a higher return due to a larger span of control. On the other hand, since the service sector has larger output elasticity with respect to labor than the manufacturing sector, employing an additional unit of labor increases service-sector output more. If the cost of labor (wages) is lower than the cost of capital($r+\tau$), the service sector would benefit more from the same amount of additional wealth. In order to investigate the effects of financial frictions on structural transformation, I must solve the model numerically.

1.3.3. Household problem

In period t, the lifetime wealth of an agent characterized by (b_t, x_t) is

$$Y_t = Y(b_t, x_t; w_t, r_t) = max\{w_t, V_M(b_t, x_t; w_t, r_t), V_S(b_t, x_t; w_t, r_t)\} + (1 + r_t)b_t \tag{23}$$

Given Y_t, an agent chooses consumption c_t and bequest b_{t+1} to maximize utility. The functional form of utility implies that agents leave a proportion $1 - \gamma$ of Y_t as a bequest.

1.3.4. Competitive Equilibrium

Let Υ_t be the distribution of bequests in period t, which evolves endogenously across periods. The initial bequest distribution Υ_0 is given.

Given ability distribution Γ and bequest distribution Υ_t, an equilibrium at period t is given by $\{r_t, w_t\}$ and allocations $c_t = c(\cdot), b_{t+1} = b(\cdot) n_j(\cdot), k_j(\cdot),\ j = \{S, M\}$ such that:

- Given $\{r_t, w_t\}$, an agent with (b_t, x_t) chooses an occupation to maximize lifetime wealth.
- Given $\{r_t, w_t\}$, entrepreneurs choose n_j to maximize profit (2) or (3).
- Given$\{r_t, w_t\}$, $l_j(b_t, x_t; w_t, r_t)$ and $a_j(b_t, x_t; w_t, r_t)$ solves (8) and $k_j(b_t, x_t; w_t, r_t) = l_j(b_t, x_t; w_t, r_t) + a_j(b_t, x_t; w_t, r_t)$, $j = \{S, M\}$.

- Given lifetime wealth (23), each agent maximizes utility.
- The labor market clears:

$$\iint_{z\in E_M(w_t,r_t)} n_M(x;w_t,r_t)\Upsilon_t(db_t)\Gamma(dx_t) + \iint_{z\in E_S(x;w_t,r_t)} n_S(x;w_t,r_t)\Upsilon_t(db_t)\Gamma(dx_t) = \iint_{z\in E^c(w_t,r_t)} \Upsilon_t(db_t)\Gamma(dx_t) \tag{24}$$

- The capital market clears:

$$\iint_{z\in E_M(w_t,r_t)} k_M(b_t,x_t;w_t,r_t)\Upsilon_t(db_t)\Gamma(dx_t) + \iint_{z\in E_S(w_t,r_t)} k_S(b_t,x_t;w_t,r_t)\Upsilon_t(db_t)\Gamma(dx_t) = \iint (b_t)\Upsilon_t(db_t)\Gamma(dx_t) \tag{25}$$

The law of motion of the wealth distribution is:
$\Upsilon_{t+1} = \int P_t(b_t,A)\Upsilon_t(db_t)$, where $P_t(b_t,A) = Pr\{b_{t+1}\in A|b_t\}$

Proposition 1.1. There exists a unique stationary equilibrium with $w > 0$, $0 < r-1 < \infty$ and invariant distribution Υ. Moreover, for any initial bequest distribution Υ_0, $0 < r-1 < \infty$, and stationary credit market frictions (τ,ϕ), the bequest distribution converges to Υ.

Proof. See Proposition 5 of António Antunes, Cavalcanti, and Villamil (2008).

1.4. Quantitative results

In this section, I calibrate the model to quantify the effect of intermediation cost and contract enforcement on entrepreneurship and structural transformation. Then I examine how the model's predictions change with variations in intermediation and enforcement costs. Next I perform counterfactual experiments for the U.S., Brazil and the Philippines using the empirical estimates of each country's financial frictions. Finally the unconstrained state-owned sector is added.

1.4.1. Calibration

The model is calibrated such that the equilibrium matches some characteristics of China. The sample period I use for calibration is 2000-2016. The following parameter values are assigned: $\alpha_S, \alpha_M, \beta_S, \beta_M$, $\tau, \phi, \varepsilon, \gamma$. Table 1.1 summarizes the parameter values.

I first set the labor shares β_S, β_M to match the share of employee compensation in value added in the service and manufacturing sectors. The labor share β_S is 0.45 and β_M is 0.39[5]. $\beta_S > \beta_M$ implies the service sector is more labor intensive. $1 - \alpha_j - \beta_j$ $(j = S, M)$ is the managerial share, measuring the share of income attributable to entrepreneurs' managerial ability. Quintin (2008) suggests using

[5] Source: National Burea of Statistics of China (NBS)

Table 1.1: Parameter values, baseline economy

Parameters	Values	Comments/Observations
α_S	0.4	Capital share in the service sector,estimated from NBS data
β_S	0.45	Labor share in the service sector, estimated from NBS data
α_M	0.51	Capital share in the non-service sector,estimated from NBS data
β_M	0.39	Labor share in the non-service sector, estimated from NBS data
τ	0.003	Intermediation cost, based on on Demirgüç-Kunt and Huizinga(1999)
γ	0.94	Calibrated to match the service sector employment / total employed(about 56%)
ϕ	0.22	Calibrated to match China's real interest rate (2%)
ε	4.7	Calibrated to match the service share of value added (51%)

the share of sole proprietors' net income that remunerates their managerial input as managerial share. I thus set $\alpha_S = 0.4$ and $\alpha_M = 0.51$ respectively such that the managerial share is 15% in the service sector and 10% in the manufacturing sector.[6]

Second, τ is measured by tax as a percentage of total bank assets, which is 0.3% (Demirgüç-Kunt and Huizinga (1999)). The other three parameters remain to be estimated: γ, the fraction of income left to the next generation; ϕ, contract enforcement; ε, curvature of the managerial ability distribution[7]. I calibrate these three parameters such that in the baseline model the real interest rate is 2%[8]; the service share of total output is 49% and the service sector employment 56%[9].

Table 1.2 compares model and data. The model matches the Chinese econ-

[6]See Appendix for details. Gollin (2002) argues that the usual approach of using employee compensation as labor income should be adjusted since it omits the labor income of entrepreneurs. According to the third adjustment proposed by Gollin, the labor and capital shares would be 60% and 40% for the service sector. These are 49% and 51% for the manufacturing sector.

[7]The cumulative distribution function of managerial ability is $\Gamma(x) = x^{1/\varepsilon}$. The managerial ability is uniformly distributed when ε equals one. When ε is greater than one, the ability distribution is concentrated among low-ability agents.

[8]Source: International Financial Statistics (IFS)

[9]Source: NBS of China. Agricultural output is excluded.

Table 1.2: Basic statistics, baseline and China economy

	China economy	baseline economy
Yearly real interest rate(%)	2	2
Service share of output (%)	49.4	49.6
Service share of employment(%)	56	56
% of entrepreneurs (%)	15	15.3
Entrepreneurs' income Gini(%)	47.2	46.2
Credit to output ratio(%)	172.3	174.1

Source: International Financial Statistics database, China NBS, CHIP (2013), IMF, BIS

omy fairly well not only for the statistics that were calibrated but for some that were not calibrated (the last two in Table 1.2). The percentage of entrepreneurs[10] over total employed is 15%[11], while in the model it is 15.3%. Data from the Bank of International Settlements and IMF show that between 2000-2016, the average total credit as a share of output in China is 172.3%, while in the model it is 174.1%.

1.4.2. Policy experiments

I now perform some quantitative experiments to explore how changes in intermediation cost and contract enforcement affect the model's six predictions: the service sector output as a fraction of total output, the service sector employment as a fraction of total employment, the service sector output per capita as a

[10] I define entrepreneurs as proprietors who take responsibility for profit and loss by themselves or with partners, having independent policy-making power.

[11] Estimated from Chinese Household Income Project 2013 (CHIP 2013), weighted as Li, Sato, and Sicular (2013) suggests.

Table 1.3: Policy experiments

	Service sector					
	size, % output	employment, % total	output per capita % baseline	total output per capita % of baseline	% of entrepreneurs	interest rate
Baseline	49.6	55.9	100	100	15.26	1.02
Part a: Intermediation costs =0.003						
$\phi = 1/2 * \phi_{base}$	53.17	60.33	95.28	96.53	15.84	-0.002
$\phi = 1/4 * \phi_{base}$	56.35	63.65	88.32	89.35	16.32	-0.51
$\phi = 1/8 * \phi_{base}$	61.79	68.73	79.98	79.77	16.668	-0.76
$\phi = 3 * \phi_{base}$	77.81	77.78	143.1	128.19	10.2	4.96
Part b: Enforcement parameter= 0.22						
$\tau = 2 * \tau_{base}$	52.42	58.63	98.2	97.49	15.29	0.97
$\tau = 4 * \tau_{base}$	54.07	60.1	91.22	90.01	15.51	0.94
$\tau = 0$	47.64	54.37	100.95	102.14	15.19	1.08
Part c						
$\phi = 1/2 * \phi_{base}, \tau = 2 * \tau_{base}$	56.27	63.05	91.32	91.38	16.03	-0.03
$\phi = 1/4 * \phi_{base}, \tau = 4 * \tau_{base}$	82.2	85.1	80.76	74.73	16.06	-0.63

fraction of baseline, total output per capita as a fraction of baseline, the percentage of entrepreneurs over total employed, and the interest rate. I first change the intermediation cost and enforcement parameters separately and then simultaneously. All statistics correspond to the steady state.

Table 1.3 part a. reports the model's predictions with the variation of enforcement parameter ϕ as intermediation costs τ is held constant. The variation of ϕ has two opposite effects: demand effect and general equilibrium effect. As for the demand effect, weaker contract enforcement decreases entrepreneurs' demand for loans for a given interest rate, which implies less capital and smaller firm size[12]. To clear the labor market, more but less productive entrepreneurs enter. Conversely, less borrowing drives down interest rates. Now entrepreneurs can be funded at a lower cost, which increases productivity and firm size. This is the

[12]Firm size is defined as the number of employees per firm.

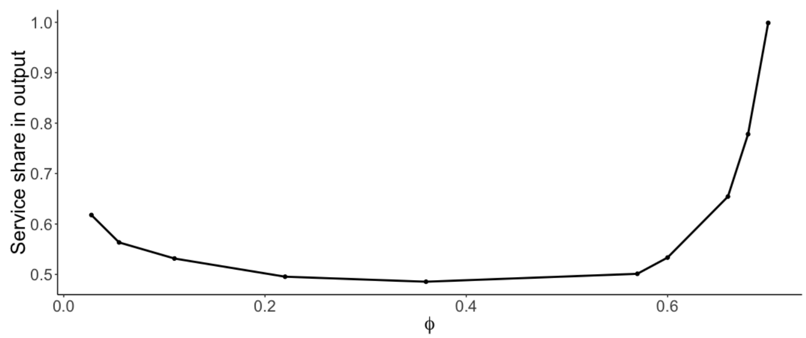


Figure 1.3: Model predicted service sector size

general equilibrium effect.

The two effects also generate different occupational shifts between the manufacturing sector and the service sector. Entrepreneurs in the manufacturing sector tend to run larger firms due to a greater span of control and therefore they have more financing needs. Moreover, the enforcement effect is stronger on capital demand than on labor demand[13], which makes manufacturing the more capital-intensive sector, more vulnerable to borrowing constraints. Therefore, the demand effect causes entrepreneurs to shift from the manufacturing sector to the service sector due to tightened borrowing constraints while the general equilibrium effect reverses the shift due to lower interest rates.

When enforcement decreases by a factor of two from the baseline economy, the service sector size increases by about 3.5% and the service output per capita decreases by about 5.7%. A larger decrease in enforcement by a factor of four increases the service sector by 6.8%, while output per capital decreases by 11.7%.

[13]From Eq.(4), $\frac{\partial n/\partial \phi}{\partial k/\partial \phi} = \alpha/(1-\beta)$, which is less than one if $\alpha < \beta$, as I assume.

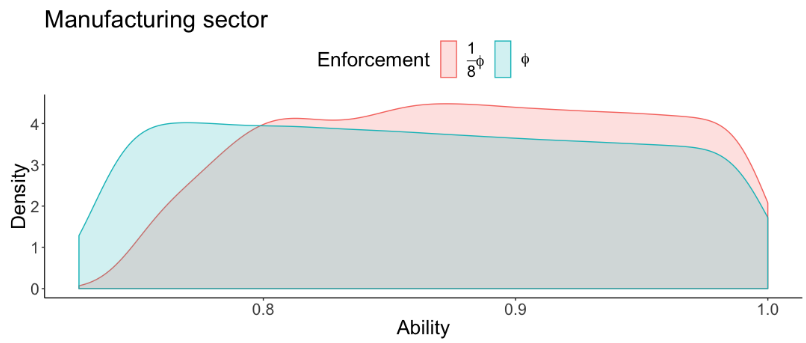
Table 1.4: Ability and firm size

	Average ability		Average firm size		ability difference	relative firm size
	S-sector	M-sector	S-sector	M-sector		
Baseline	0.5813	0.8620	5.2737	5.9547	0.2807	1.1291
$\phi = 1/2 * \phi_{base}$	0.5758	0.8688	5.1322	5.6134	0.2931	1.0938
$\phi = 1/4 * \phi_{base}$	0.5712	0.8728	5.0742	5.2530	0.3016	1.0352
$\phi = 1/8 * \phi_{base}$	0.5764	0.8819	5.0107	4.9636	0.3055	0.9906

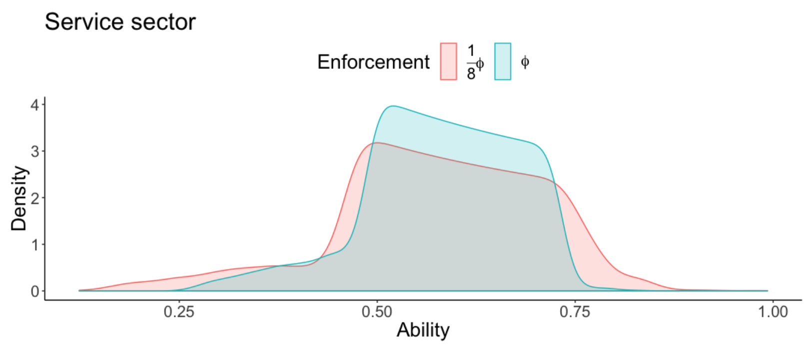
When enforcement increases by a factor of three, the service sector increases as well as the output per capita. However, the relation between the service sector size and enforcement is not monotonic. The association is positive when enforcement is sufficiently high and is negative when enforcement is sufficiently low, as Figure 1.3 shows. Since enforcement and output per capita are positively related, the non-monotonic relationship between the service sector size and enforcement implies a hump-shape relation between the manufacturing sector size and total output per capita.

Such a hump-shape manufacturing development pattern is consistent with empirical evidence, which shows the manufacturing sector may first grow relative to the service sector and then decline over development.

Table 1.4 presents the effect of enforcement on ability and firm size distribution across sectors. A drop in ϕ makes average ability more dispersed across sectors. Due to low enforcement, only highly talented entrepreneurs can overcome the credit constraints by high profitability. Low talented entrepreneurs in the manufacturing sector may shift to the smaller-scale service sector. Due to the demand effect, more but less productive agents enter and start businesses in the



(a) Manufacturing: ability distribution

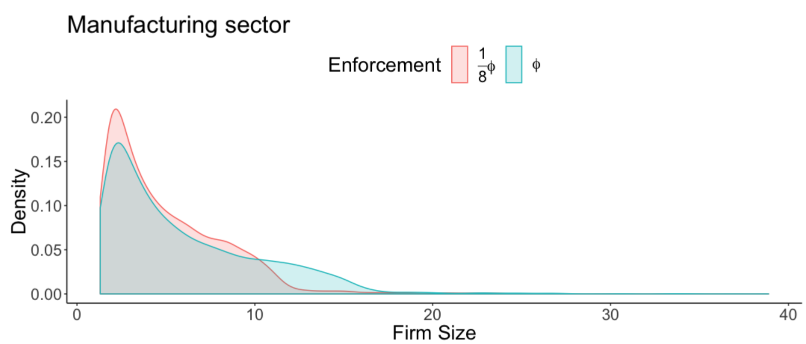


(b) Services: ability distribution

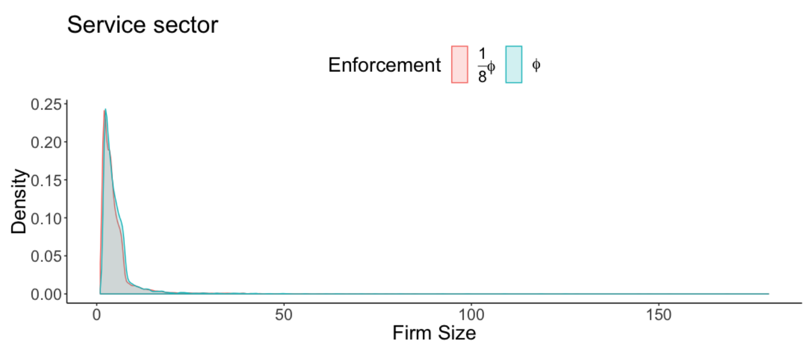
Figure 1.4: Ability distribution

service sector. The ability is concentrated at a higher level for the manufacturing sector (Figure 1.4a) while the ability distribution in the service sector is more dispersed (Figure 1.4b).

Firm size in the manufacturing sector, defined as the number of workers per enterprise, shrinks (Figure 1.5a) due to low enforcement, while such an effect on the service sector is not obvious (Figure 1.5b). Thus, the relative firm size in



(a) Manufacturing: firm size distribution



(b) Services: firm size distribution

Figure 1.5: Firm size distribution

manufacturing to that in services decreases as enforcement decreases[14].

In the limiting case $\phi = 1$, the service sector dominates, and the manufacturing sector vanishes. The interest rate is extremely high which makes it much more costly to operate firms in the manufacturing sector. Accordingly, entrepreneurs shift from the manufacturing sector to the service sector.

I now verify the impacts of intermediation costs, τ, on the size of the ser-

[14] The predictions are consistent with Buera, Kaboski, and Shin (2011).

vice sector and productivity. Similar to ϕ, the demand effect and the general equilibrium effect also apply. An increase in τ raises the cost of borrowing and thus lowers entrepreneurs' demand for loans for a given interest rate. Smaller loan size implies less capital input and firm size shrinks. Consequently, more but less productive entrepreneurs enter to clear the labor market. Conversely, a fall in the demand for loans decreases the interest rate. Firm size and productivity increase since highly talented entrepreneurs now can be funded at lower costs. Table 1.3.b shows the predictions when τ varies. A rise in the intermediation cost increases the service sector size as well as service sector employment. Output per capita for both the service sector and the whole economy decreases.

Table 1.3.c reports the results of experiments in which both enforcement and intermediation costs are changed. Effects are much stronger than the separate change. When both ϕ and τ are worsened by a factor of four, the service size is 82.2% while it is around 55% in both separate-change cases.

1.4.3. Counterfactual analysis

I now use independent estimates of intermediation costs and contract enforcement for Brazil, the Philippines and the U.S., and Chinese values for all other parameters to compare the model's predictions with data observed in these three countries. Intermediation costs are measured as intermediary taxes over banks' total assets: 1.1% in Brazil, 0.3% in the Philippines and 0.5% in the U.S.

In Antonio Antunes, Cavalcanti, and Villamil (2008), two measures are used to assess the enforcement parameter ϕ: $dejuris$ and $defacto$ measures. The *dejuris* measure uses a legal rights index from Porta, Lopez-de-Silanes, Shleifer, and Vishny (1998), which evaluates how well the company laws and bankruptcy laws are designed to protect investors. The index follows, ranging from 0 to 10, with higher scores indicating that laws are better designed to promote access to credit. The *defacto* measure defines investor protection by the previous legal rights index times a rule of law indicator. The rule of law index is computed by Kaufmann, Kraay, and Mastruzzi (2011) measuring how well written laws are enforced in practice.

Here, I use the *defacto* measure to estimate the contract enforcement.[15] Multiplying the ratio of the *defacto* measure for a given country to the Chinese value by the benchmark calibration ϕ yields the enforcement values[16].

Table 1.5 shows the model predictions for the size of the service sector and GDP per employed in Brazil, the Philippines and the U.S. The service sector size increases from 49.6% to 64.3% when intermediation costs and enforcement fall from the Chinese to the Brazilian level, implying the financial frictions account for 65% of the difference in the service sector size between Brazil and China. For the Philippines, enforcement explains roughly 47% of the difference in service sector size. The model estimates the U.S. service sector size as 54% which is far below 77.4% in the data. Different factor intensities across sectors may account for the discrepancy between model predictions and the data. Unlike Brazil

[15] According to the legal rights index, China has an index of 7, the index for Brazil, the U.S. and the Philippines are 3, 9 and 3. As for the rule of law, China has a score of 4.03. The scores for Brazil, the U.S. and the Philippines are 4.06, 8.18 and 4.1.

[16] The respective enforcement values for the U.S., Brazil and the Philippines are 0.57 and 0.11 and 0.09.

Table 1.5: Counterfactual analysis, De facto ϕ

	ϕ	τ	Service sector size, %, output	Service sector output per capita, % baseline
Baseline	0.22	0.003	49.6	100
Brazil(data)	0.11	0.011	72.1	138.8
Model's predictions				
Intermediation costs	0.22	0.011	54.35	93.44
Enforcement	0.11	0.003	53.19	95.25
Intermeditation and enforcement	0.11	0.011	64.3	83.2
Philippines(data)	0.09	0.003	58.8	70.75
Model's predictions				
Intermediation costs	0.22	0.003	49.6	100
Enforcement	0.09	0.003	53.89	93.9
Intermeditation and enforcement	0.09	0.003	53.89	93.9
United States(data)	0.57	0.005	77.4	427.23
Model's predictions				
Intermediation costs	0.22	0.005	49.29	96.87
Enforcement	0.57	0.003	53.23	111.56
Intermeditation and enforcement	0.57	0.005	54.32	111.09

and the Philippines whose service sector is more labor-intensive like China's, the variation in factor intensity in the U.S. is quite small across the service and the manufacturing sectors (Valentinyi and Herrendorf (2008)). Hence, the general setup abstracts factor-share differences from multi-sector models analyzing the U.S. economy (Hsieh and Klenow (2007), Buera, Kaboski, and Shin (2011)).

The model only captures a small portion of the differences in the service sector productivity across the Philippines, the U.S. and China. Antonio Antunes, Cavalcanti, and Villamil (2008) demonstrates that financial frictions can explain a larger fraction of differences in output per capita if the interest rate is exogenous. When the interest rate is endogenous, the demand effect is partially offset by the general equilibrium effect and the overall effect of output per capita is limited. Brazil's measured enforcement and intermediation costs are worse than China's, but output per capita in the service sector is 38% higher. Other factors such as TFP may explain such discrepancies between model predictions and the data.

1.4.4. State-owned sector

In the benchmark model, entrepreneurs face the same credit constraints. In China, however, state-owned enterprises (SOEs)[17] are not subject to the same financial constraints as their private sector competitors. SOEs have long enjoyed preferential access to domestic credit and below-market interest rates on loans. SOEs play a crucial role in the Chinese economy and can be found in all sectors

[17] SOEs are defined as enterprises in which all assets are owned by the state. SOEs are either centrally owned or owned by provincial or local governments.

of the economy. Over one third of all publicly listed firms are SOEs. They possess over half of market capitalization and employ about 20% of the labor force. As in Quadrini (2000), where an unconstrained sector dominated by large production units is added to the constrained entrepreneur sector, I now add an unconstrained state-owned sector to the model to see how the results change. The state-owned sector has a representative firm in the service sector and the manufacturing sector respectively. The firms produce with a constant return-to-scale production function. For $j = M, S$, K_j and N_j denote capital and labor for industry j and A_j is a TFP parameter. The state-owned firm's output Y_j is given by

$$Y_j = A_j K_j^{\theta_j} N_j^{1-\theta_j}, \theta_j \in (0,1), A_j > 0, j = S, M \tag{26}$$

The state-owned firms take factor prices (w, r) as given, choosing labor and capital to maximize profits. The first order conditions are:

$$w_j = (1-\theta) A_j (\frac{K_j}{N_j})^{\theta} \tag{27}$$

$$(1+r) = \theta A_j (\frac{K_j}{N_j})^{\theta-1} \tag{28}$$

The equilibrium conditions (24) and (25) of the benchmark model now become :

$$\iint_{z \in E_M(w_t, r_t)} n_M(x; w_t, r_t) \Upsilon_t(db_t) \Gamma(dx_t) + \iint_{z \in E_S(x; w_t, r_t)} n_S(x; w_t, r_t) \Upsilon_t(db_t) \Gamma(dx_t)$$
$$+ N_S(w_t, r_t) + N_M(w_t, r_t) = \iint_{z \in E^c(w_t, r_t)} \Upsilon_t(db_t) \Gamma(dx_t) \tag{29}$$

Table 1.6: Parameter values, baseline economy with state-owned sector

Parameters	Values	Comments/Observations
α_S	0.4	Capital share in the service sector,estimated from NBS data
β_S	0.45	Labor share in the service sector, estimated from NBS data
α_M	0.51	Capital share in the non-service sector,estimated from NBS data
β_M	0.39	Labor share in the non-service sector, estimated from NBS data
τ	0.003	Intermediation cost, based on on Demirgüç-Kunt and Huizinga(1999)
γ	0.875	Calibrated to match the service sector employment over total employed(about 56%)
ϕ	0.41	Calibrated to match China's real interest rate (2%)
ε	5.5	Calibrated to match the service share of value added (51%)
A_S	0.36	Calibrated to match the sOEs' employment over total employed (21%)
A_M	0.56	Calibrated to match the SOEs' capital over total capital (36%)

$$\iint_{z\in E_M(w_t,r_t)} k_M(b_t,x_t;w_t,r_t)\Upsilon_t(db_t)\Gamma(dx_t) + \iint_{z\in E_S(w_t,r_t)} k_S(b_t,x_t;w_t,r_t)\Upsilon_t(db_t)\Gamma(dx_t) + K_S(w_t,r_t) + K_M(w_t,r_t) = \iint (b_t)\Upsilon_t(db_t)\Gamma(dx_t) \tag{30}$$

There are four additional parameters to be calibrated: the capital share for two sectors, θ_M and θ_S and TFP parameters, A_M and A_S. According to the adjustments suggested by Gollin (2002), I set $\theta_M = 0.45$ and $\theta_S = 0.4$. Given each period's (w,r), A_m and A_s evolve over time to satisfy (27) and (28). I calibrate $A_M = 0.56$ and $A_S = 0.36$ such that 21% of aggregate labor and 36% of capital are employed in the state-owned sector[18]. Parameters α_M, α_S, β_M, β_S and τ are the same as in Table 1.1. The same targets are used to calibrate ϕ,γ and ε. Table 1.6 reports the values. Compared to the benchmark model, γ decreases which implies a higher level of initial wealth and credit supply since $(1-\gamma)$ is

[18]Source: NBS and China Economic Census Yearbook

Table 1.7: Basic statistics, baseline and China economy with state-owned sector

	Chinese economy	baseline economy
Yearly real interest rate(%)	2	2
Service share of output(%)	49.4	50
Service share of employment(%)	56	55
Capital used in the state-owned sector(%)	36	36
Labor employed in the state-owned sector(%)	21	21
% of entrepreneurs (%)	15	13.2
Entrepreneurs' income Gini (%)	47.2	38
Credit to output ratio(%)	172.3	307

the proportion of lifetime wealth left as a bequest. The enforcement parameter ϕ almost doubles, suggesting the credit constraint (11) is loosened. Adding an unconstrained state-owned sector seems to relax entrepreneurs' credit constraints. Table 1.7 compares the model's prediction with data. The model matches the target statistics (lines 1-5), but it underestimates the percentage of entrepreneurs and entrepreneurs' income Gini. The private credit to output ratio is considerably higher than the Chinese economy observation 123.3%.

Policy experiments in Table 1.8 are similar to Table 1.3.c. The TFP parameters are not fixed at the baseline value so I can test whether financial frictions generate an endogenous fall in TFP as Pratap and Urrutia (2012) and Buera, Kaboski, and Shin (2011) suggest.

In the policy experiment, if enforcement and intermediation costs are both worsened by a factor of two, total output per capita decreases by about 15%, while there is only a 9% decline in the benchmark model (Table 1.3.c). The service-sector productivity does not experience the same drop as the benchmark model.

Table 1.8: Policy experiments

	Service sector						
	size, % output	employment, % total	output per capita % baseline	total output per capita % of baseline	% of entrepreneurs	interest rate	% of capital employed in SOEs
Baseline	50	55	100	100	13.2	1.02	36
Endogenous TFP							
$\phi = 1/2 * \phi_{base}, \tau = 2 * \tau_{base}$	81.2	80.34	99.7	85.7	13.71	0.36	60.13
$\phi = 1/4 * \phi_{base}, \tau = 4 * \tau_{base}$	94.9	92.47	85.69	75.08	13.652	0.18	73.92
Exogenous TFP							
$\phi = 1/2 * \phi_{base}, \tau = 2 * \tau_{base}$	81.2	80.34	99.7	85.7	13.71	0.36	60.13
$\phi = 1/4 * \phi_{base}, \tau = 4 * \tau_{base}$	94.9	92.47	85.69	75.08	13.652	0.18	73.92

A weaker general equilibrium effect in the new model may account for this. With lower enforcement and higher intermediation costs, the demand effect implies a drop in the demand for loans; therefore less capital is employed in production, firm size shrinks and productivity decreases. The general equilibrium effect, however, counterbalances part of the negative effect by lower interest rates. The decline of loan demand drives interest rates down and entrepreneurs can be funded at lower costs. Table 1.8 shows the interest rate as 0.36 while it is much lower -0.03 in the benchmark model. Therefore, the general effect in the benchmark model is stronger, offsetting a larger part of the negative demand effect on productivity. For the same reason, entrepreneurs in the manufacturing sector are subject to more strict credit constraints in the new model. Compared to the benchmark model, there are now more high-talented entrepreneurs in the manufacturing sector shifting to the service sector, which counteracts a larger amount of the productivity loss in the service sector caused by financial frictions. As a consequence, output per capita in the service sector is not as low as that in the benchmark model. Both enforcement parameter ϕ and bequest ratio $1-\gamma$ increase by adding a state-owned sector. The effect of financial frictions on output still deepens. A fall in TFP may account for this. As table 8 shows, TFP parameters for both sectors decrease as enforcement and intermediation costs are worsened. The state-owned firms become less productive but employ a larger percentage of capital. Such capital misallocation may lower productivity[19].

1.5. Conclusion

This paper develops a quantitative framework to study the impacts of financial frictions on structural transformation. Two types of financial frictions, intermediation costs and financial contract enforcement, distort the allocation of capital and managerial talent across sectors and generate sizable effects on sector sizes, sector-level employment, output per capita, ability distribution and firm size. I find that both a drop in intermediation costs and a rise in enforcement have almost equal positive effects on output per capita for both the service sector and the whole economy. Increased intermediation costs would increase the size of the service sector as well as the number of workers employed in the service sector, while enforcement and the service sector size do not have a monotonic relationship. The association is positive when the enforcement level is sufficiently high and it is negative when the enforcement level is sufficiently low. This implies a hump-shape development pattern of manufacturing: an initial growth in the manufacturing sector size and later a decline as total output per capita increase.

[19] Hsieh and Klenow (2009) find misallocation of capital and labor generates differences in manufacturing TFP. My model implies financial frictions might be one source of such misallocation.

I use independent estimates of intermediation costs and contract enforcement in Brazil, the U.S. and the Philippines to explain observed differences in the service sector across countries. For developing countries, such as Brazil and the Philippines, intermediation costs and enforcement can account for about 65% and 47% of differences in the service sector size respectively. Regarding differences in productivity, the model fails to account for many of the differences in output per capita across countries. Adding an unconstrained state-owned sector tends to exacerbate the effects of financial friction because of a decline in TFP for the state-owned firms. I model sector differences by the factor intensity and span of control. Alternatively, I can differentiate sectors by sector-specific fixed costs (Buera, Kaboski, and Shin (2011)) or by intensity of producing intermediate goods (Moro (2012)). Moreover, I do not distinguish products produced in the two sectors. Incorporating two different products and relative price is a promising way for my model to better explain the productivity differences across countries.

2. SPILLOVERS AND STRATEGIC COMMITMENT IN R&D

2.1. Introduction

Much of the extensive literature on innovation and market structure in industrial organization assumes that research and development (R&D) take place before the associated output is produced, or in other words, that the underlying game is a two-stage game, with strategic commitment in the R&D decision.[20] In such settings, it is widely known, at least since Brander and Spencer (1983), that firms will use R&D for strategic purposes, in the sense that they engage in excessive R&D as a way to ensure higher market shares in the product market.

However, in some cases, the R&D investment effort of each firm is not (perfectly) observable by its rival. This may be due to a variety of different factors: firms may be operating in different regions; firms may be relatively successful at not revealing the extent and/or the nature of their R&D operations (secrecy); and potential difficulties in relating partially observed R&D results or outcomes and final cost reductions. In cases where such factors play a significant role in the overall strategic interaction among the rival firms, the appropriate model for investigating the interplay between R&D and product market decisions may well be a one-stage game with both decisions taken simultaneously by each firm.

Although the literature on the topic has largely tended to follow the two-stage formulation, there are a number of important studies in which the one-stage

[20] The full list is too long to enumerate, but we can at least retain Spence (1984), d'Aspremont and Jacquemin (1988), Kamien, Muller, and Zang (1992), Rabah Amir (2000), among others.

paradigm was adopted. A partial list includes the following articles: Dasgupta and Stiglitz (1980), and Brander and Spencer (1983). In particular, the latter authors also argue that, in the one-stage game, the firms do not engage in excessive R&D, but in fact, their R&D levels correspond to the cost-minimizing levels of R&D for the outputs they end up producing at equilibrium.

The main goal of Brander and Spencer (1983) was to provide a comparison of the market performances of the one-stage and the two-stage models, for the case of a Cournot duopoly with general functional forms, but without spillovers in R&D. The purpose of this paper is to consider a linear version (i.e., linear demand and costs) of the duopoly model of Brander and Spencer (1983), to include R&D spillovers in the model, and to go beyond the issues studied by Brander and Spencer (1983). This purpose is accomplished with relative ease, since the linear structure of the duopoly allows for easily computed closed-form Nash equilibrium, both for the R&D and output levels, and also for the corresponding profits and social welfare. Exploiting this analytically convenient and widely used structure, we are able to provide a substantially more thorough comparison of the market performances implied by the one-stage and the two-stage models of R&D and product market competition. In doing so, relative to the classical paper by Brander and Spencer (1983) , we obviously lose on the side of generality of the setting and thus also of the results.

It is worth observing that, from a methodical standpoint, the present exercise is essentially a special case of the more frequently addressed issue in full-fledged economic dynamics of comparing open-loop and closed-loop Nash Equilibria in dynamic games (see e.g., Rabah Amir (1996) and Wiszniewska-Matyszkiel (2014), among many others).

We consider a Cournot duopoly in a market for a homogeneous good with firms investing in R&D and simultaneously deciding on output levels. Each firm benefits from its own R&D and from (involuntary and prior unpreventable) spillovers in the rival's investment. There are two well-known models in the context of an oligopoly with cost-reducing R&D. The first, introduced by d'Aspremont and Jacquemin (1988), henceforth AJ, posits a framework of duopolistic R&D/Cournot competition with spillover effects that are additive in R&D outputs. The second, proposed by Spence (1984) and Kamien, Muller, and Zang (1992), henceforth KMZ, postulates the presence of spillover effects on R&D inputs. We adopt the latter spillover model, as modified by Rabah Amir (2000), to capture in an equivalent manner the ubiquitous quadratic R&D cost function proposed by AJ and widely adopted in the follow-up literature.

In the first part of the paper, we characterize the unique Nash equilibrium of the one-stage Cournot duopoly model with R&D. The main findings may be summarized as follows: each firm's autonomous R&D investment is decreasing in the spillover parameter, but the effective R&D expenditure (its own plus spillover) is independent of the spillover parameter. Therefore, each firm's equilibrium output, industry price and thus consumer surplus are also independent of spillovers. It also follows that each firm's equilibrium profit and social welfare are increasing in the spillover level.

The fact that effective R&D expenditure is independent of the spillover parameter is a borderline reflection of the conventional view that technological progress is slower in economic environments where imperfect appropriability of know-how is higher (see e.g., Griliches (1995), J. I. Bernstein and Nadiri (1988) and Scotchmer (2004)). It is worth recalling that per-firm R&D investment is indeed decreasing in the spillover level in the present model, with this outcome being a weaker form of the same conventional view (as is easily seen by inspection).

In the second part of the paper, we provide a comparison of the one-stage game and the sequential game (two-stage game) in terms of the same dimensions of market performance. Recall that Brander and Spencer (1983) have conducted a similar exercise in the absence of spillover. They found that, relative to the one-stage model, the two-stage model will increase the R&D undertaken, lower industry profits, and (under some general conditions) improve welfare. However, incorporating spillover in R&D inputs, we find that the market performance comparison depends in a critical manner on the spillover level. In short, while we confirm the Brander-Spencer results for small spillover levels (specifically, a spillover parameter less than $1/2$), the results are reversed for high spillover levels. The one exception is equilibrium profit, which is strictly higher in the one-stage game for all spillover levels other than $1/2$, while for the latter (knife-edge case), the profit levels are exactly the same in the two games (in fact, the solutions then fully coincide).

In the last part of the paper, we extend the analysis to the case with more than two firms. The comparison results of R&D expenditure, consumer surplus, and profit under the two-firm setting still hold. While the welfare comparison result does not generalize to the n-firm case.

This paper joins an extensive literature devoted to the interplay between strategic competitive forces and R&D with spillover effects. Besides the articles already cited, recent contributions include Martin (1996), Martin (2002), Cosandier, Feo, and Knauff (2017), Gama, Maret, and Masson (2019) in industrial organization; as well as McDonald and Poyago-Theotoky (2017), and Amir, Gama, and Werner (2017) in environmental economics.

This paper is organized as follows: Section 2.2 introduces the one-stage game and the symmetric equilibrium R&D/output solutions, along with corresponding profit and social welfare. Section 2.3 compares the one-stage game with the standard sequential game (two-stage) in terms of overall market performance. Section 2.4 extends the analysis to n-firm oligopolies. Section 2.5 provides a brief conclusion.

2.2. The one-stage game

We start with a description of a symmetric Cournot duopoly in a market for a homogeneous good with deterministic process R&D opportunities. The industry is a homogeneous-product Cournot duopoly with linear demand $P(q_1+q_2) = a - b(q_1+q_2)$, where $b > 0$ and q_1 and q_2 denote the outputs of firm 1 and 2. The firms have the same initial unit cost $c > 0$.

The process R&D opportunities are subject to (involuntary) mutual R&D spillovers. The R&D process follows the KMZ model, with spillovers taking place in R&D inputs, or investments.[21] Let y_1 and y_2 be the expenditures on R&D by firms 1 and 2, taken to be their R&D decisions. The effective cost reduction for firm i is $\sqrt{\frac{1}{\gamma}(y_i+\beta y_j)}, (i=1,2)$ where $\gamma > 0$ is a measure of the effectiveness of R&D and $\beta \in [0,1]$ is the spillover parameter, which captures the proportion of the rival's R&D input that spills over. Given the same initial unit cost c for two firms, the final unit cost for firm i is

$$c_i = c - \sqrt{\frac{1}{\gamma}(y_i+\beta y_j)}.$$

We depart from the standard R&D literature in industrial organization by assuming that the entire interaction is a one-shot game, i.e., firms choose both R&D levels and outputs simultaneously (and not sequentially as in much of the literature). Due to the spillover effects, the effective action sets for R&D expenditure are inter-related via

$$\Omega_i = \{y_i : y_i \leq c^2\gamma - \beta y_j\},\ i,j = 1,2.$$

To guarantee that both firms remain in the market even under very unequal R&D choices, we make the standard assumption, which is maintained throughout the paper.

(A1) $a > 2c$.

[21]Thus we are following the spillover specification introduced by Spence, 1984, and later adopted by many authors, including KMZ and Rabah Amir, Evstigneev, and Wooders (2003). The alternative specification, due to AJ yields a significantly different model, as clarified by Rabah Amir (2000).

Given the rival's R&D expenditure and output (y_j, q_j), firm i solves[22]

$$\max_{(y_i,q_i)} \pi_i(y_i, q_i, y_j, q_j) = q_i[a - b(q_i + q_j)] - q_i[c - \sqrt{\frac{1}{\gamma}(y_i + \beta y_j)}] - y_i \tag{31}$$

The first-order conditions with respect to q_i and y_i are given by:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2bq_i - bq_j - c + \sqrt{1/\gamma(y_i + \beta y_j)} = 0$$

$$\frac{\partial \pi_i}{y_i} = \frac{1}{2\gamma} \frac{q_i}{\sqrt{1/\gamma(y_i + \beta y_j)}} - 1 = 0$$

It can easily be verified that there is

$$y^* = \begin{cases} \frac{\gamma(a-c)^2}{(1+\beta)(6b\gamma-1)^2} & \text{if } b\gamma > \frac{a}{6c} \\ \frac{\gamma c^2}{1+\beta} & \text{if } b\gamma \leq \frac{a}{6c} \end{cases} \tag{32}$$

and

$$q^* = \begin{cases} \frac{2\gamma(a-c)}{6b\gamma-1} & \text{if } b\gamma > \frac{a}{6c} \\ \frac{a}{3b} & \text{if } b\gamma \leq \frac{a}{6c} \end{cases} \tag{33}$$

We refer below to the top line in (32) and (33) as an interior equilibrium and to the bottom line in (32) and (33) as a boundary equilibrium.

Next, we evaluate the other standard indicators of market performance.

[22] $\pi_i(y_1, y_2, p_1, p_2)$ is the profit for firm i, henceforth referred to as $\pi_i(y_1, y_2)$.

The corresponding equilibrium profit is easily calculated to be

$$\pi^*(y^*,y^*) = \begin{cases} \frac{\gamma(a-c)^2[4b\gamma(1+\beta)-1]}{(1+\beta)(6b\gamma-1)^2} & \text{if } b\gamma > \frac{a}{6c} \\ \frac{a^2(1+\beta)-9b\gamma c^2}{9b(1+\beta)} & \text{if } b\gamma \leq \frac{a}{6c} \end{cases} \tag{34}$$

Social welfare is given by (given equilibrium R&D level y^* and output level q^* by each firm)

$$W(y^*,y^*) = \int_0^{2q^*} (a-bt)dt - 2(c-\sqrt{(1+\beta)y^*/\gamma})q^* - 2y^* \tag{35}$$

After some calculation, the social welfare level is reduced to

$$W(y^*,y^*) = \begin{cases} \frac{2\gamma(a-c)^2(8b\gamma(1+\beta)-1)}{(6b\gamma-1)^2(1+\beta)} & \text{if } b\gamma > \frac{a}{6c} \\ \frac{4a^2(1+\beta)-18b\gamma c^2}{9b(1+\beta)} & \text{if } b\gamma \leq \frac{a}{6c} \end{cases} \tag{36}$$

We now investigate the comparative statics properties of this Nash equilibrium with respect to changes in the spillover parameter β. We clearly have both for the interior and the boundary solutions:

$$\frac{\partial y^*}{\partial \beta} < 0.$$

This is in line with standard intuition that, as β gets higher, R&D becomes more of a public good, so free-riding increases, thus leading to declining investments. This effect forms one of the long-standing stylized facts about innovation in general: see e.g., Griliches (1995)and J. Bernstein and Nadiri (1988) empirical evidence and detailed overall discussions. Yet in the empirical literature, there is often some ambiguity as to whether it is per-firm R&D investment or actual technological progress that declines in industries with higher spillover effects. In the present model, the latter interpretation would amount to the effective R&D level, i.e., its own R&D plus spillover R&D, which is decreasing in the spillover parameter, clearly the stronger (more stringent) interpretation. It is seen by inspection that, with the effective R&D level $Y^* = (1+\beta)y^*$, we have

$$\frac{\partial Y^*}{\partial \beta} = 0, \text{ and thus } \frac{\partial q^*}{\partial \beta} = 0.$$

In other words, effective R&D follows the aforementioned stronger interpretation of declining technological progress only in a borderline sense. Thus, firms adjust their levels of R&D to a varying spillover parameter in such a way as to maintain constant technological progress, and thus also constant output, industry price, and consumer surplus.

It is easy to verify that

$$\frac{\partial \pi^*(y^*, y^*)}{\partial \beta} > 0.$$

The intuition for this result is actually obvious from the invariance of the effective R&D level. Indeed, as β increases, each firm's revenue and production costs remain constant (from the above results), so the only effective change is that each firm is paying for less and less R&D while it ends up with same final R&D. In other words, a higher spillover leads only to savings in their own R&D investment, all other variables of interest here remaining constant.

Finally, it follows directly from the previous comparative statics results that[23]

$$\frac{\partial W^*(y^*,y^*)}{\partial \beta} > 0.$$

As we shall see in the next section, these results reflect significant differences with respect to the more standard two-stage game.

2.3. A comparison of the one-stage and the two-stage models

In this section, we compare our present one-stage model and the well-known model by Kamien, Muller, and Zang (1992) (KMZ)(two-stage model) in terms of resulting propensity for R&D and overall market performance. Some of these comparisons were conducted by Brander and Spencer (1983) in a setting with general functional forms but no spillover effects. By adopting the standard specification of a duopoly with linear demand and costs, and quadratic R&D costs, we are able to expand the scope of the market performance comparison, and do so for each possible level of the spillover parameter.

To that end,we begin with a short review of the relevant results from the KMZ model, as reported in Rabah Amir (2000).

[23]This can also be verified directly by a straightforward computation and signing of $\frac{\partial W^*(y^*,y^*)}{\partial \beta}$.

2.3.1. The KMZ model

The KMZ model is based on the standard two-stage game of R&D and product market competition. The decision variables in the first stage are the R&D expenditures, $y_1, y_2 \geq 0$, by two firms. In the second stage, firms engage in a Cournot competition in a market for a homogeneous product with linear demand $P = a - b(q_1 + q_2)$ and common marginal cost c, where $b > 0$ and q_1, q_2 are the outputs of firm 1 and 2.

The R&D process follows the version of KMZ model as adapted by Rabah Amir (2000). With $\beta \in [0,1]$ denoting the spillover parameter in R&D investment, the final cost reduction of firm i, given by $y_1, y_2 \geq 0$, is $\sqrt{\frac{1}{\gamma}(y_i + \beta y_{-i})}$. The payoff of firm i as a function of R&D expenditure levels y_1 and y_2 is

$$\pi_i(y_1, y_2) = \frac{1}{9b}[a - c + 2\sqrt{\frac{1}{\gamma}(y_i + \beta y_j)} - \sqrt{\frac{1}{\gamma}(y_j + \beta y_i)}]^2 - y_i \tag{37}$$

The two-stage game symmetric R&D expenditure is

$$y^* = \begin{cases} \frac{\gamma(2-\beta)^2(a-c)^2}{(1+\beta)(9b\gamma-2+\beta)^2} & \text{if } b\gamma > \frac{(2-\beta)a}{9c} \\ \frac{\gamma c^2}{1+\beta} & \text{if } b\gamma \leq \frac{(2-\beta)a}{9c} \end{cases} \tag{38}$$

The top line in (38) is the interior solution and the bottom line in (38) is the boundary solution.

The corresponding profit is

$$\pi(y^*,y^*) = \begin{cases} \frac{\gamma[9b\gamma(1+\beta)-(2-\beta)^2](a-c)^2}{(1+\beta)(9b\gamma-2+\beta)^2} & \text{if } b\gamma > \frac{(2-\beta)a}{9c} \\ \frac{a^2(1+\beta)-9b\gamma c^2}{9b(1+\beta)} & \text{if } b\gamma \leq \frac{(2-\beta)a}{9c} \end{cases} \tag{39}$$

In the remainder of this section, we restrict attention to the interior solution comparison for one-stage model and the two-stage model.

2.3.2. Market performance comparison

We first assume that the interior solution conditions for both models hold, i.e., $b\gamma > \frac{(2-\beta)a}{9c}$ and $b\gamma > \frac{a}{6c}$. We thus establish the following assumption (maintained throughout this section) such that the two conditions hold for any β:

(A2) $b\gamma > \frac{2a}{9c}$.

We now compare our one-stage model and KMZ model (two-stage model) in terms of R&D expenditure, profits, output and welfare.

Taking difference in R&D levels yields

$$y^*(2)-y^*(1) = \frac{3(a-c)^2 b\gamma^2}{(1+\beta)(9b\gamma-2+\beta)^2(6b\gamma-1)^2}(2\beta-1)[2(2-\beta)-3b\gamma(7-2\beta)] \tag{40}$$

where $y^*(1)$ and $y^*(2)$ denote the R&D expenditure under perfect symmetry in one-stage game and two-stage game respectively.

Given **(A2)**, we can easily derive

$$2(2-\beta)-3b\gamma(7-2\beta) < 0 \tag{41}$$

Hence, $y^*(2) > y^*(1)$ if and only if $\beta < 1/2$. Let $a = 2.2, b = 1, c = 1, \gamma = 1$, Figure 2.1 depicts the result.

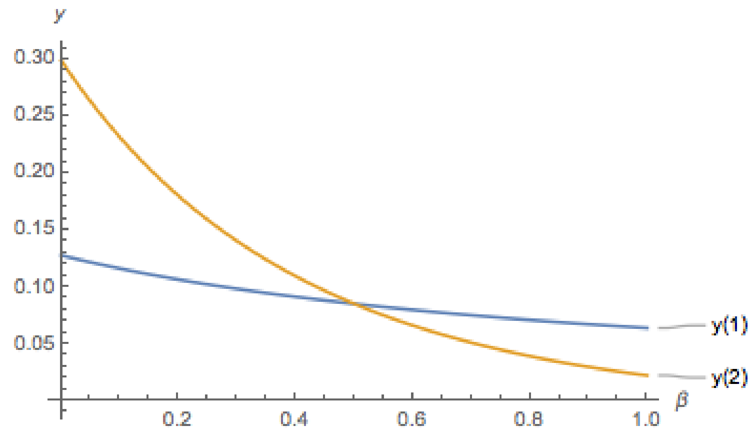


Figure 2.1: R&D expenditure: one-stage vs. two-stage

Figure 2.1 shows that in the absence of spillovers, i.e., $\beta = 0$, firms in the two-stage framework use more R&D, which confirms Brander and Spencer (1983)'s findings. As β gets higher, the R&D levels for both models decrease. This is in line with the intuition that higher spillovers lower the propensity of firms to engage in R&D due to the free rider effect in public goods. Moreover, firms in the two-stage game may use R&D for strategic purposes rather than simply to minimize costs. Such strategic use of R&D leads to more severe free rider effect. Thus, the R&D expenditure in the two-stage model decreases more rapidly than that in the one-stage model.

The comparison of output and consumer surplus is similar. The previous section suggests that firms in the one-stage model adjust their levels of R&D to a varying spillover parameter to maintain constant effective R&D levels and thus constant output. In the two-stage model, effective R&D level Y^* is calculated to be

$$Y^* = \frac{\gamma(2-\beta)^2(a-c)^2}{(9b\gamma-2+\beta)^2} \tag{42}$$

We have

$$\frac{\partial Y^*}{\partial \beta} < 0, \text{ and thus } \frac{\partial q^*}{\partial \beta} < 0.$$

In contrast to the one-stage game, firms in the two-stage game follow declining technological progress. With a higher spillover parameter, firms reduce output, raising industry price, and thus decrease consumer surplus. Figure 2.2 provides an output comparison.

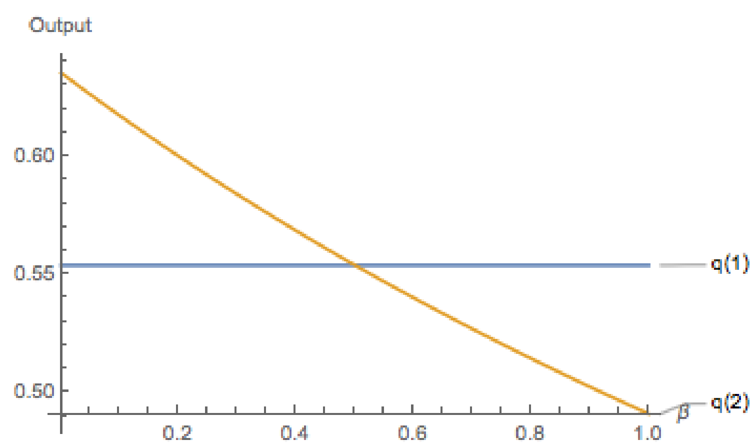


Figure 2.2: Output: one-stage vs. two-stage

The dynamics of profit to a varying β in the two-stage model are not obvious. We can compute a threshold β' such that

$$\frac{\partial \pi^*(y^*, y^*)}{\partial \beta} > 0 \text{ when } \beta < \beta'$$

and

$$\frac{\partial \pi^*(y^*,y^*)}{\partial \beta} < 0 \text{ when } \beta \geq \beta'$$

Let $\pi^*(1)$ and $\pi^*(2)$ be the profits under perfect symmetry in the one-stage game and two-stage game respectively. Comparing profits yields

$$\pi^*(2) - \pi^*(1) = \frac{b\gamma(a-c)^2}{(1+\beta)(9b\gamma-2+\beta)^2(6b\gamma-1)^2}(2\beta-1)^2(5-\beta-27b\gamma) \quad (43)$$

Simple calculation shows that $\pi(2) \leq \pi(1)$; equality holds if and only if $\beta = 1/2$. Figure 2.3 characterizes the profit comparison.

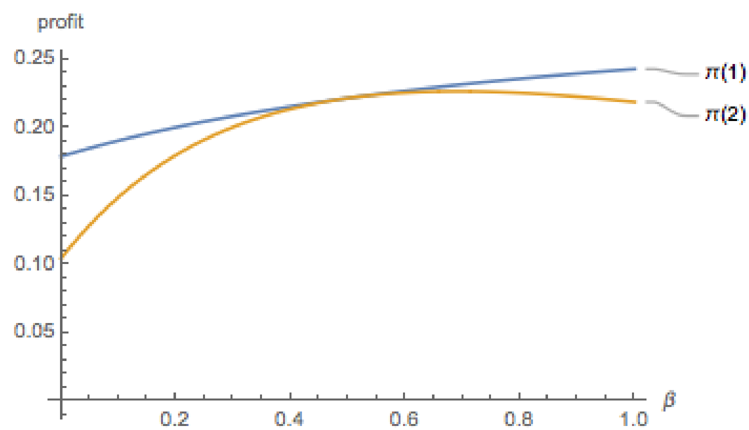


Figure 2.3: Profit: one-stage vs. two-stage

Finally, the welfare in the one-stage model increases in β, but the relationship in the two-stage model is not monotonic. When the spillover parameter is small enough, a higher β will reduce consumer surplus while increasing profit. Welfare will be improved if the positive effect on profit outweighs the negative effect on consumer surplus. When the spillover parameter exceeds the threshold

β', increasing β will lower both consumer surplus and profit and thus decrease welfare. Specifically, the social welfare for the KMZ model is

$$W(y^*, y^*) = \frac{2\gamma(a-c)^2[18b\gamma(\beta+1)-(\beta-2)^2]}{(9b\gamma+\beta-2)^2(1+\beta)} \tag{44}$$

Figure 2.4 displays the variation of welfare in response to β. As β increases, each firm's profit in a one-stage model is higher than that in a two-stage model if and only if $\beta > 1/2$.

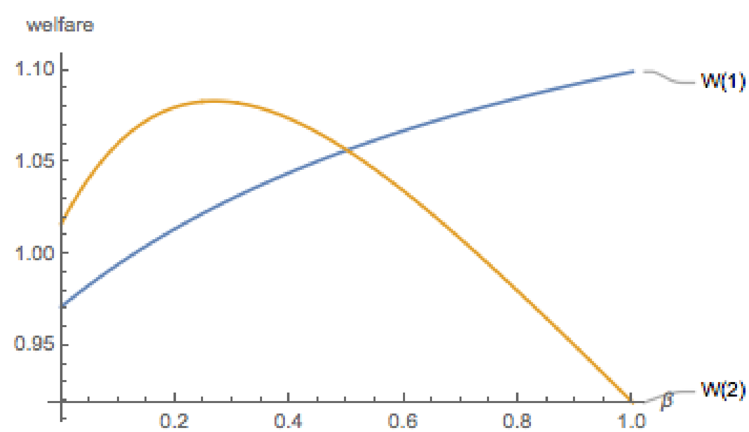


Figure 2.4: Welfare: one-stage vs. two-stage

Overall, strategic use of R&D will increase the R&D undertaken, lowers output and improves welfare only for small spillover levels (specifically, a spillover parameter less than 1/2); the results are reversed, however, for high spillover levels. The one exception is profit, which is higher in the one-stage game for all spillover levels, with equality if and only if β is $1/2$.

We have thus established the following results:

Proposition 2.1. Under perfect symmetry,

1. each firm undertakes more R&D in the one-stage game than in the two-stage model if and only if $\beta > 1/2$;
2. consumer surplus has the same comparison results;
3. each firm earns more profit than in the two-stage model if and only if $\beta \neq 1/2$.
4. the one-stage game has superior welfare if and only if $\beta > 1/2$.

2.4. More than two firms

In section 2.3, we compare the one-stage and two-stage games in the context of a Cournot duopoly model. In this section, we extend the analysis to n-firm oligopolies. Consider an industry with n firms, maintaining the assumptions and notations of previous sections.

Let y_i be the R&D expenditure by firm i, $(i = 1, 2, ...n)$. The effective cost reduction for firm i is determined by each firm's individual R&D expenditure

$$X_i = \sqrt{\frac{1}{\gamma}(y_i + \beta \sum_{j=1, j\neq i}^{n} y_j)},$$

Given the common initial cost c, the effective action sets for R&D expenditure are

$$\Omega_i = \{y_i : y_i \leq c^2\gamma - \beta \sum_{j=1, j\neq i}^{n} y_j\},\ i, j = 1, 2...n$$

One-stage game

It is straightforward to generalize the payoff function for firm i

$$\pi_i = q_i[a - b\sum_{j=1}^{n} q_j] - q_i[c - \sqrt{\frac{1}{\gamma}(y_i + \beta \sum_{j=1, j\neq i}^{n} y_j)}] - y_i \tag{45}$$

We now can solve the equilibrium for the one-stage model. The symmetric per-firm R&D and per-firm output are

$$y_n^*(1) = \begin{cases} \frac{\gamma(a-c)^2}{(2b\gamma(n+1)-1)^2(1+\beta(n-1))} & \text{if } b\gamma > \frac{a}{2c(n+1)} \\ \frac{\gamma c^2}{1+(n-1)\beta} & \text{if } b\gamma \leq \frac{a}{2c(n+1)} \end{cases} \tag{46}$$

$$q_n^*(1) = \begin{cases} \frac{2\gamma(a-c)}{2b\gamma(n+1)-1} & \text{if } b\gamma > \frac{a}{2c(n+1)} \\ \frac{a}{b(n+1)} & \text{if } b\gamma \leq \frac{a}{2c(n+1)} \end{cases} \tag{47}$$

Two-stage game

We restrict consideration to the subgame perfect equilibrium of the game. Firm i's profit is

$$\pi_i = \frac{1}{(n+1)^2 b}\left(a - c + nX_i - \sum_{j=1, j\neq i}^{n} X_j\right)^2 - y_i, \tag{48}$$

where $X_i = \sqrt{\frac{1}{\gamma}(y_i + \beta \sum_{j=1, j\neq i}^{n} y_j)}$ and $X_j = \sqrt{\frac{1}{\gamma}(y_j + \beta \sum_{k=1, k\neq j}^{n} y_k)}$, $i, j = 1, 2 \ldots n$.

The subgame perfect equilibrium is

$$y_n^*(2) = \begin{cases} \frac{\gamma(a-c)^2(n(1-\beta)+\beta)^2}{(1+(n-1)\beta)((n+1)^2 b\gamma-(n(1-\beta)+\beta))^2} & \text{if } b\gamma > \frac{a(n(1-\beta)+\beta)}{c(n+1)^2} \\ \frac{\gamma c^2}{1+(n-1)\beta} & \text{if } b\gamma \leq \frac{a(n(1-\beta)+\beta)}{c(n+1)^2} \end{cases} \tag{49}$$

$$q_n^*(2) = \begin{cases} \frac{\gamma(a-c)(n+1)}{(n+1)^2 b\gamma-(n(1-\beta)+\beta)} & \text{if } b\gamma > \frac{a(n(1-\beta)+\beta)}{c(n+1)^2} \\ \frac{a}{b(n+1)} & \text{if } b\gamma \leq \frac{a(n(1-\beta)+\beta)}{c(n+1)^2} \end{cases} \tag{50}$$

To restrict our attention to the interior solutions, we assume that the interior solution conditions for models hold, i.e.,

$$b\gamma > \frac{a}{2c(n+1)}, \text{and } \; b\gamma > \frac{a(n(1-\beta)+\beta)}{c(n+1)^2}$$

for any $n \geq 2$ and $\beta \in [0,1]$. We therefore keep the assumption

(A2): $b\gamma > \frac{2a}{9c}$.

Taking the difference between the R&D expenditure in the one-stage and two-stage models, we arrive at the following condition:

for any $n > 2$, $y_n^*(1) > y_n^*(2)$ if and only if $\beta > 1/2$.

Thus, the result of R&D comparison in the proposition holds for the n-firm case. We also prove that the comparison results of consumer surplus and profit in the proposition generalize to the n-firm setting.

However, the welfare comparison result does not generalize to arbitrary n.

$$W_n^*(1) = \frac{n\gamma(a-c)^2(2(n+2)b\gamma(1+\beta(n-1))-1)}{(2b\gamma(n+1)-1)^2(1+\beta(n-1))} \tag{51}$$

$$W_n^*(2) = \frac{n\gamma(a-c)^2((n+1)^2b\gamma(1+(n-1)\beta)(n+2)-2(\beta+n(1-\beta))^2)}{2(1+(n-1)\beta)((n+1)^2b\gamma-(n(1-\beta)+\beta))^2} \tag{52}$$

$sign(W_n^*(1)-W_n^*(2)) = sign(2\beta-1)(D)$,

where

$$D = 2(n+2)(n-1)^2\beta^2+\beta(n-1)(4b\gamma(n^2+1)(n+3)-3n^2-9n-2)-2b\gamma(n+1)^2(n-3)+n^2-3n-2$$

When $n > 2$,there exists a β^* defined by $D(\beta^*) = 0$ such that $D < 0$ for all $\beta < \beta^*$ and $D > 0$ for all $\beta > \beta^*$. Simulation indicates that β^* lies in $(0, 0.034)$.

Therefore, when $n > 2$, $W^*(1)-W^*(2) > 0$ if and only if $\beta < \beta^*$ or $\beta > 1/2$. And $W^*(1)-W^*(2) < 0$ if and only if $\beta^* < \beta < 1/2$.

Proposition 2.2. Under perfect symmetry,

1. With more than two firms, proposition 2.1 (1-3) still hold.

2. When there are more than two firms, the one-stage game has superior welfare if and only if $\beta < \beta^*$ or $\beta > 1/2$.

2.5. Conclusion

This paper has analyzed a one-stage Cournot duopoly in a market for a homogeneous good with firms deciding simultaneously on process R&D and output levels. R&D is subject to input spillovers, i.e., in investment spillovers. We argue that this setting might well be more appropriate than the more commonly used two-stage model, under some conditions on the industry environment and the R&D process.

We derive a simple characterization of the unique Nash equilibrium of the one-stage model. We show that each firm's autonomous R&D investment is decreasing in the spillover parameter, but the effective R&D expenditure (own plus spillover parts) is independent of the spillover parameter. Therefore, each firm's equilibrium output, industry price and consumer surplus are also independent of spillovers. Hence each firm's equilibrium profit and social welfare are increasing in the spillover level.

In the second part of the paper, we provide a comparison of the one-stage game and the sequential game (two-stage game) in terms of the same dimensions of market performance. In the absence of spillovers, Brander and Spencer (1983) have found that, relative to the one-stage model, the two-stage model increases R&D, lowers industry profits, and improves social welfare. However, with spillover in R&D inputs, we find that the market performance comparison depends in a critical manner on the spillover level. In short, while we confirm the Brander-Spencer results for small spillover levels (specifically, a spillover parameter less than $1/2$), the results are reversed for high spillover levels. The one exception is equilibrium profit, which is higher in the one-stage game for all spillover levels, with equality if and only if the spillover parameter is $1/2$. The comparison results of R&D expenditure, consumer surplus, and profit under the two-firm setting hold for n-firm oligopolies. But the welfare comparison result does not generalize to the n-firm setting.

The conclusions from this comparative analysis are that the two possible models for investigating the interplay between R&D and product market competition yield significantly different results, and the resulting market performance depends in important ways on the level of R&D spillovers.

3. ON THE SCOPE FOR A PRISONER'S DILEMMA IN R&D IN A ONE-STAGE GAME

3.1. Introduction

Much of the literature in industrial organization postulates that research and development (henceforth, R&D) takes place before the associated output is produced by firms. In such cases, it is well-known that firms use R&D for the strategic purpose of enhancing their market shares in the product market (Brander and Spencer (1983)).

However, in some industry environments, the R&D investment effort of each firm is not (perfectly) observable by the rival. This important feature may be due to technological reasons related to the production process, geographical reasons, successful anti industrial espionage measures, among others. In this paper, we examine a version of the R&D/Cournot competition model where R&D expenditure and output are simultaneously determined by each firm. In other words, the overall interaction then becomes a one-stage game.[24]

We consider a Cournot duopoly in a market for a homogeneous good with R&D. The firms are subject to invest in R&D and also benefit from additive spillovers in rival's investment. We first analyze the case by assuming that the entire interaction is a one stage game. Then, in order to investigate the possibility of a prisoner's dilemma in R&D, we then set up a two-stage game by adding an initial commitment stage. In the first stage, the firms commit to an irreversible decision,

[24] Dasgupta and Stiglitz (1980), analyze simultaneous models.

whether to conduct any R&D or not. Such a binary choice will be referred to as Invest or Not Invest. In the second stage, firms observe the announcement choices and decide both R&D levels and outputs simultaneously. In this formulation, we follow Bacchiega, Lambertini, and Mantovani (2008) who consider a modified version of d'Aspremont and Jacquemin (1988), henceforth AJ. This model posits a two-stage framework of duopolistic R&D/Cournot competition with spillover effects that are additive in R&D outputs. Bacchiega, Lambertini, and Mantovani (2008) add an initial period to this model, wherein firms decide whether or not invest conduct R&D, they find that there exists a prisoner's dilemma when spillover effects are sufficiently small. Burr, Knauff, and Stepanova (2013) build on a version of the model in Kamien, Muller, and Zang (1992)(KMZ) as adapted by Rabah Amir (2000). Their main results on the possibility of a prisoner's dilemma for a sub-region of the parameter space are similar. The key characteristic of this region is that it involves small values of the spillover parameter.[25]

Finally, We provide a comparison of our results to similar findings in Burr, Knauff, and Stepanova (2013), in terms of dominant strategy in R&D and the possibility of a prisoner's dilemma. In contrast to Burr, Knauff, and Stepanova (2013), we find that investing R&D is not a dominant strategy under our general conditions, and there does not exist a prisoner's dilemma regardless of the

[25] As brought forth by the detailed comparison in Amir (2000), the two different ways of modeling additive R&D spillovers yield two distinct models that are different in some significant respects. In other words, whether spillover effects are additive in R&D outputs (as pioneered by AJ; see also Jin and Troege (2006)) or R&D inputs (as pioneered by Spence (1984) and followed up by KMZ and Rabah Amir, Evstigneev, and Wooders (2003)) matters for a number of different conclusions reached via the use of these models.

spillover parameter and the cost of R&D. The main result of this paper is then that for a prisoner's dilemma in R&D to emerge, it is necessary for firms to observe their R&D decisions before determining outputs. In other words, the same strategic forces that induce firms to over-invest in R&D for strategic market share expansion in the two-stage game (as in Brander and Spencer (1983)) also frame firms in a prisoner's dilemma situation regarding their R&D possibilities. That the conduct of process R&D by competing firms may follow the logic of a prisoner's dilemma and thus constitute a privately unwelcome outcome has been observed in a number of different studies dealing with somewhat different settings, in particular Rabah Amir, Halmenschlager, and Jin (2011), Bacchiega, Lambertini, and Mantovani (2008), Burr, Knauff, and Stepanova (2013), and Rabah Amir, Halmenschlager, and Knauff (2017).

This paper is organized as follows. Section 3.2 introduces a one-stage game and its symmetric equilibrium R&D expenditure, output and profit. Section 3.3 describes a new game with initial commitment and discusses the possibilities of a prisoner's dilemma in R&D. Section 3.4 compares the results in section 3.3 to similar results for the two-stage game of R&D and output choices.

3.2. One-stage game of R&D/Cournot competition

We consider a one-stage model of Cournot duopoly in a market for a homogeneous good, wherein firms may conduct process R&D. The product market competition features a linear demand $P(q_1+q_2)=a-b(q_1+q_2)$, where $a,b>0$ and q_1 and q_2 are the outputs of firm 1 and 2.

Firms invest in process R&D and also benefit from spillovers in rival's investment. Own and spillover investment are additive, and lead to an effective cost reduction for each firm. The R&D process follows the KMZ model (i.e., spillovers are in R&D investment). Let y_1 and y_2 be the expenditures on R&D by firm 1 and 2. The effective cost reduction for firm i is $\sqrt{\frac{1}{\gamma}(y_i+\beta y_j)}$ where $\gamma > 0$ is a measure of the effectiveness of R&D and $\beta \in [0,1]$ is a spillover parameter that captures the proportion of the rival's R&D inputs that spill over to the firm. . Given the same initial unit cost c for two firms, the final cost reduction for firm i is

$$c_i = c - \sqrt{\frac{1}{\gamma}(y_i+\beta y_j)}.$$

Unlike most previous models of Cournot duopoly with R&D, here the two firms choose both R&D levels and output levels simultaneously[26].

Due to the spillover effects, firm i's effective action set for R&D expenditure is

$$\Omega_i = \{y_i : y_i \le c^2\gamma - \beta y_j\},\ i,j = 1,2.$$

To guarantee that both firms stay in the market, we make the standard assumption (to be maintained throughout the paper):

(A1) $a > 2c$.

[26]This is a key departure from the standard R&D literature in industrial organization where R&D and outputs are decided sequentially in a two-stage game: See e.g., AJ, KMZ, Rabah Amir (2000), among many others.

Given the rival's R&D expenditure and output (y_j, q_j), firm i solves[27]

$$\max_{(y_i,q_i)} \pi_i(y_i,q_i,y_j,q_j) = q_i[a-b(q_i+q_j)] - q_i[c-\sqrt{\frac{1}{\gamma}(y_i+\beta y_j)}] - y_i \tag{53}$$

The first-order conditions with respect to q_i and y_i are given by:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2bq_i - bq_j - c + \sqrt{1/\gamma(y_i+\beta y_j)} = 0$$

$$\frac{\partial \pi_i}{y_i} = \frac{1}{2\gamma}\frac{q_i}{\sqrt{1/\gamma(y_i+\beta y_j)}} - 1 = 0$$

It is easy to verify that there is a unique and symmetric equilibrium (y^*, y^*, q^*, q^*), given by

$$y^* = \begin{cases} \frac{\gamma(a-c)^2}{(1+\beta)(6b\gamma-1)^2} & \text{if } b\gamma > \frac{a}{6c} \\ \frac{\gamma c^2}{1+\beta} & \text{if } b\gamma \leq \frac{a}{6c} \end{cases} \tag{54}$$

$$q^* = \begin{cases} \frac{2\gamma(a-c)}{6b\gamma-1} & \text{if } b\gamma > \frac{a}{6c} \\ \frac{a}{3b} & \text{if } b\gamma \leq \frac{a}{6c} \end{cases} \tag{55}$$

We refer below to the top line in (54) and (55) as the interior equilibrium and to the bottom line in (54) and (55) as the boundary equilibrium. The corre-

[27] $\pi_i(y_1, y_2, p_1, p_2)$ is the profit for firm i. Henceforth referred to as $\pi_i(y_1, y_2)$.

sponding equilibrium profit is

$$\pi^*(y^*, y^*) = \begin{cases} \frac{\gamma(a-c)^2[4b\gamma(1+\beta)-1]}{(1+\beta)(6b\gamma-1)^2} & \text{if } b\gamma > \frac{a}{6c} \\ \frac{a^2(1+\beta)-9b\gamma c^2}{9b(1+\beta)} & \text{if } b\gamma \leq \frac{a}{6c} \end{cases} \tag{56}$$

3.3. The R&D game with initial pre-commitment to R&D

In this section, we consider a two-stage game for the one-stage game of the previous section by adding an initial period to the latter wherein the two firms make a binary announcement as to their R&D intentions. In this first stage, the two firms simultaneously commit to an irreversible decision, whether to conduct any R&D or not. This binary choice is referred to as Invest or Not Invest. In the second stage, firms choose both R&D levels and outputs simultaneously accordingly. The second stage follows the one-shot game described in section 3.2, with the important modification that any firm that has chosen Not Invest in the first stage is committed to spending zero on R&D in the second stage. Such a firm can then decide only on an output level in the second stage.

Thus, the four possible subgames following the first-period binary announcement may be described as follows. If both firms choose Invest in the first stage, the consequent subgame is identical to the one-shot game described in the above section. If both firms choose Not Invest in the first stage, the subgame that follows is merely the standard Cournot duopoly without R&D. Finally, if one firm chooses Invest and the other chooses Not Invest, then in the following subgame, a firm with R&D expenditure competes with a no-R&D firm. We evaluate the equilibrium decisions and profits below.

Suppose firm 1 decides to invest $y_1 > 0$ while firm 2 chooses not to invest (i.e., $y_2 = 0$). Then firm 1' profit is

$$\max_{(y_1,q_1)} \pi_1(y_1,q_1,0,q_2) = q_1[a-b(q_1+q_2)] - q_1[c-\sqrt{\frac{1}{\gamma}y_1}] - y_1 \tag{57}$$

The first order conditions are then

$$\frac{\partial \pi_1}{\partial q_1} = a - 2bq_1 - bq_2 - c + \sqrt{\frac{1}{\gamma}y_1} = 0 \tag{58}$$

$$\frac{\partial \pi_1}{y_1} = \frac{1}{2\gamma}\frac{q_1}{\sqrt{\frac{1}{\gamma}y_1}} - 1 = 0 \tag{59}$$

If firm 2 chooses zero R&D, its profit is

$$\max_{q_2} \pi_2(y_1,q_1,0,q_2) = q_2[a-b(q_1+q_2)] - q_2[c-\sqrt{\frac{1}{\gamma}\beta y_1}] \tag{60}$$

The first order condition is

$$\frac{\partial \pi_2}{\partial q_2} = a - 2bq_2 - bq_1 - c + \sqrt{\frac{1}{\gamma}\beta y_1} = 0 \tag{61}$$

Solving (58), (59) and (61) yields

$$\bar{y}_1 = \begin{cases} \frac{\gamma(a-c)^2}{(6b\gamma+\sqrt{\beta}-2)^2} & \text{if } b\gamma > \frac{a+c-c\sqrt{\beta}}{6c} \\ \gamma c^2 & \text{if } b\gamma \leq \frac{a+c-c\sqrt{\beta}}{6c} \end{cases} \tag{62}$$

$$\bar{q}_1 = \begin{cases} \frac{2\gamma(a-c)}{6b\gamma+\sqrt{\beta}-2} & \text{if } b\gamma > \frac{a+c-c\sqrt{\beta}}{6c} \\ \frac{a+c-\sqrt{\beta}c}{3b} & \text{if } b\gamma \leq \frac{a+c-c\sqrt{\beta}}{6c} \end{cases} \tag{63}$$

$$\bar{q}_2 = \begin{cases} \frac{(a-c)(2b\gamma+\sqrt{\beta}-1)}{b(6b\gamma+\sqrt{\beta}-2)} & \text{if } b\gamma > \frac{a+c-c\sqrt{\beta}}{6c} \\ \frac{a-2c+2\sqrt{\beta}c}{3b} & \text{if } b\gamma \leq \frac{a+c-c\sqrt{\beta}}{6c} \end{cases} \tag{64}$$

$$\pi_1(\bar{y}_1, 0) = \begin{cases} \frac{\gamma(a-c)^2(4b\gamma-1)}{(6b\gamma+\sqrt{\beta}-2)^2} & \text{if } b\gamma > \frac{a+c-c\sqrt{\beta}}{6c} \\ \frac{(a+c-\sqrt{\beta}c)^2-9b\gamma c^2}{9b} & \text{if } b\gamma \leq \frac{a+c-c\sqrt{\beta}}{6c} \end{cases} \tag{65}$$

$$\pi_2(\bar{y}_1, 0) = \begin{cases} \frac{(a-c)^2(2b\gamma+\sqrt{\beta}-1)^2}{b(6b\gamma+\sqrt{\beta}-2)^2} & \text{if } b\gamma > \frac{a+c-c\sqrt{\beta}}{6c} \\ \frac{(a-2c+2\sqrt{\beta}c)^2}{9b} & \text{if } b\gamma \leq \frac{a+c-c\sqrt{\beta}}{6c} \end{cases} \tag{66}$$

To analyze the subgame-perfect equilibria of the two-stage game, we calculate the subgame-perfect equilibria of each of the four subgames described above and then collapse the game back to the first-stage decision, Invest or Not Invest. This reduction leads to a simple 2×2 matrix.

Table 3.1: R&D game

		Firm 2	
		Invest	Not Invest
Firm 1	Invest	$\pi_1(y^*,y^*),\pi_2(y^*,y^*)$	$\pi_1(\bar{y},0),\pi_2(\bar{y},0)$
	Not Invest	$\pi_1(0,\bar{y}),\pi_2(0,\bar{y})$	$\pi_1(0,0),\pi_2(0,0)$

3.3.1. Reduction to a one-stage R&D game

To find the subgame-perfect equilibrium of the two-stage game, we use the equilibrium payoffs calculated above to replace the subgames in the game tree. Then the two-stage game described in the above section can be reduced to a one-stage game in the binary announcement (first-period) decisions. The resulting 2×2 normal form R& D investment game can be represented as Table 3.1.

1. $\pi_1(y^*,y^*) = \pi_2(y^*,y^*) = \pi(y^*,y^*)$ is as given in (56).

2. $\pi_1(0,0) = \pi_2(0,0) = \frac{(a-c)^2}{9b}$ is the standard Cournot equilibrium profit without R&D.

3. $\bar{y}$ is a firm's R&D best response to a rival conducting zero R&D. This is given by (62). (63) and (64) provide the output for the R&D-conducting firm and the no-R&D firm respectively. $\pi_1(0,\bar{y}) = \pi_2(\bar{y},0)$ and $\pi_1(\bar{y},0) = \pi_2(0,\bar{y})$, which are presented in (65) and (66).

3.3.2. Scope for a prisoner's dilemma in R&D

This section examines the scope for a prisoner's dilemma for the two-action game presented above. In other words, the question here is whether each firm has a dominant strategy to announce Invest, when in fact both firms would be better off agreeing to choose Not Invest.

For a prisoner's dilemma to hold, we require that investing in R&D be a dominant strategy for both firms, i.e., that (say for firm 1)

$$\pi_1(\bar{y},0) > \pi_1(0,0) \tag{67}$$

and

$$\pi_1(y^*,y^*) > \pi_1(0,\bar{y}). \tag{68}$$

Clearly, (67) always holds since $\bar{y}$ is the best response to the rival's zero R&D expenditure. The region where (68) holds is shown in Figure 1 and 2.

Therefore, announcing Invest in R&D is a dominant strategy for both firms only when the spillover parameter β and the cost of R&D tend to be small. It is rather intuitive since a higher cost of R&D lowers the firms' propensity to engage in R&D.

Furthermore, such a prisoner's dilemma requires that (y^*,y^*) be Pareto dominated by $(0,0)$, or $\pi_i(y^*,y^*) < \pi_i(0,0)$, that is,

$$\frac{\gamma(a-c)^2[4b\gamma(1+\beta)-1]}{(1+\beta)(6b\gamma-1)^2} < \frac{(a-c)^2}{9b} \tag{69}$$

for the interior solution, and

$$\frac{a^2(1+\beta)-9b\gamma c^2}{9b(1+\beta)} < \frac{(a-c)^2}{9b} \tag{70}$$

for the boundary solution. (69) holds for the interior solution if and only if

$$b\gamma < \frac{1+\beta}{3+12\beta} \tag{71}$$

and (70) holds for the boundary solution if and only if

$$b\gamma > \frac{(1+\beta)(2a-c)}{9c} \tag{72}$$

A simple calculation shows that (71) and (72) contradict the condition for interior and boundary solutions given in (54). Therefore, there is no prisoner's dilemma for both the interior and the boundary solutions. We report the result just proved formally now.

Proposition 3.1 The two-stage game presented above incorporates no prisoner's dilemma in R& D for both interior and boundary solutions.

Figure 3.1 and Figure 3.2 show the region that investing R&D is a dominant strategy ($a = 2.2, c = 1$). Figure 3.1 is for the interior solution and Figure 3.2 is for the boundary solution. They also depict the region where Not Investing is a dominant strategy.

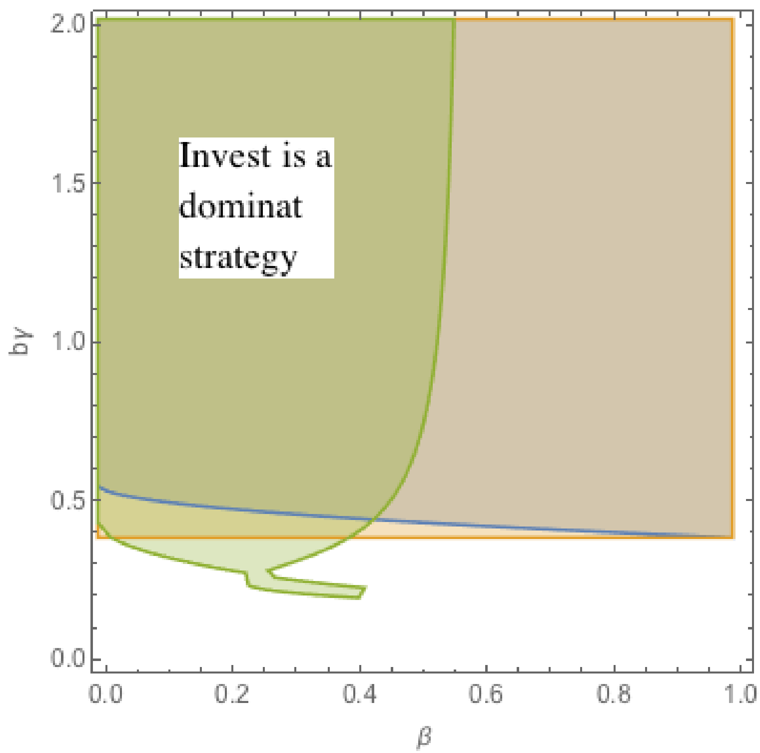


Figure 3.1: The region of dominant strategy for interior solution in $(\beta, b\gamma)$ space

3.4. Comparison with Burr, Knauff, and Stepanova (2013)

This section compares the results of the present paper to similar findings obtained in Burr, Knauff, and Stepanova (2013).[28] Burr, Knauff, and Stepanova, 2013 incorporate a three-stage game, where firms commit to do R&D in the first stage and choose specific R&D expenditures and outputs sequentially in the ensuing two stages. The two-stage subgame follows the KMZ model as adapted by Rabah Amir (2000). Thus the aim of this section is to compare the scope for a

[28]We only show the interior solution comparison in this section, the boundary solution case is similar.

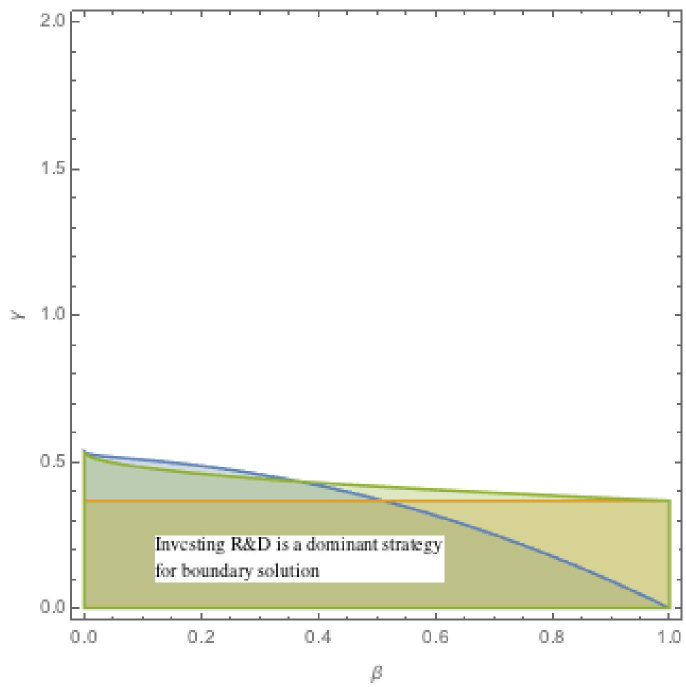


Figure 3.2: The region of dominant strategy for boundary solution in $(\beta, b\gamma)$ space

prisoner's dilemma in R& D for the one-stage model versus the two-stage model of R&D and product market competition. To this end, we first review the results for the two-stage KMZ model.

3.4.1. The KMZ model

We introduce the KMZ model used in Burr, Knauff, and Stepanova (2013). The KMZ model is based on the standard two-stage game of R&D and product market competition. The decision variables in the first stage are the R&D expenditures, $y_1, y_2 \geq 0$, by two firms. In the second stage, firms engage in a Cournot competition in a market for a homogeneous product with linear demand

$P = a - b(q_1 + q_2)$ and common marginal cost c, where $b > 0$ and q_1, q_2 are the outputs of firm 1 and 2. With $\beta \in [0,1]$ denoting the spillover parameter in R&D investment, the final cost reduction of firm i, given $y_1, y_2 \geq 0$, is $\sqrt{\frac{1}{\gamma}(y_i + \beta y_{-i})}$. The payoff of firm i as a function of R&D expenditure levels y_1 and y_2 is

$$\pi_i(y_1, y_2) = \frac{1}{9b}[a - c + 2\sqrt{\frac{1}{\gamma}(y_i + \beta y_j)} - \sqrt{\frac{1}{\gamma}(y_j + \beta y_i)}]^2 - y_i \tag{73}$$

The two-stage game symmetric R&D expenditure is

$$y^* = \begin{cases} \frac{\gamma(2-\beta)^2(a-c)^2}{(1+\beta)(9b\gamma-2+\beta)^2} & \text{if } b\gamma > \frac{(2-\beta)a}{9c} \\ \frac{\gamma c^2}{1+\beta} & \text{if } b\gamma \leq \frac{(2-\beta)a}{9c} \end{cases} \tag{74}$$

The top line in (74) is the interior solution and the bottom line in (74) is the boundary solution.

The corresponding profit is

$$\pi(y^*, y^*) = \begin{cases} \frac{\gamma[9b\gamma(1+\beta)-(2-\beta)^2](a-c)^2}{(1+\beta)(9b\gamma-2+\beta)^2} & \text{if } b\gamma > \frac{(2-\beta)a}{9c} \\ \frac{a^2(1+\beta)-9b\gamma c^2}{9b(1+\beta)} & \text{if } b\gamma \leq \frac{(2-\beta)a}{9c} \end{cases} \tag{75}$$

3.4.2. The comparison of the scope for a prisoner's dilemma

By adding an initial commitment stage to the KMZ model with a binary announcement for each firm, thus generating a three-stage game, Burr, Knauff, and Stepanova (2013) prove the following results. They show that investing R&D is always a dominant strategy for both firms, that is (say for firm 1), $\pi_1(\bar{y},0) > \pi_1(0,0)$ and $\pi_1(y^*,y^*) > \pi_1(0,\bar{y})$. In addition, when the spillover parameter is small enough (i.e., below a threshold that they identify), one has $\pi_i(y^*,y^*) < \pi_i(0,0)$. In other words, (y^*,y^*) is Pareto dominated by $(0,0)$. Therefore, such a three-stage formulation embodies a prisoner's dilemma in R&D under some conditions[29].

In contrast to Burr, Knauff, and Stepanova (2013), in the present paper, the region where investing R&D is a dominant strategy shrinks. In addition, the prisoner's dilemma disappears all together.

As Brander and Spencer (1983) suggest, the strategic use of R&D in the KMZ game increases firms' propensity to engage in R&D since they foresee that they can increase their market share in the output market by investing more in R&D. Therefore, when R&D and output are sequentially determined, investing in R&D is more likely to be a dominant strategy. Moreover, the over-investment in R&D may lead to a prisoner's dilemma. In contrast, in our one-stage R&D/output choice, the level of R&D chosen is tailored to minimize the total cost of producing the equilibrium level of output, taking into account both R&D and production costs for each firm. There is no extra R&D that is conducted for the sake of market share expansion. This is reflected in the absence of a prisoner's dilemma in R&D. In other words, this comparison establishes a tight connection between the strategic use of R&D for market share gain (as discussed in Brander and Spencer, 1983) and the prisoner's dilemma in R&D.

In terms of welfare, Burr, Knauff, and Stepanova (2013) show that con-

[29]Specifically, $\frac{a(2-\beta)}{9c} < b\gamma < \frac{(1+\beta)(2-\beta)}{27\beta}$, which requires that $\beta < 0.2$.

ducting the Nash equilibrium levels of R&D always leads to higher social welfare than no R&D, or $W(y^*,y^*) > W(0,0)$. The resulting R&D from the prisoner's dilemma, which is something firms wish they could avoid, actually improves social welfare. Thus, there is no prisoner's dilemma at the social level. R&D leads to higher industry output and hence increases consumer surplus. Such a positive effect on consumer surplus outweighs the negative effect on profit since overall welfare rises. Our paper shows that when (y^*,y^*) is a Nash equilibrium [30], the equilibrium R&D levels increase both profits and social welfare than no R&D. That is, $\pi_i(y^*,y^*) > \pi_i(0,0)$ and $W(y^*,y^*) > W(0,0)$. Simple computation also implies the social returns to R&D exceed the firms' returns. This is widely supported by much empirical literature, in particular J. I. Bernstein and Nadiri (1988) and Scotchmer (2004).

[30]The region where (y^*,y^*) is a Nash equilibrium is given by Figure 3.1

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APPENDIX:APPENDIX TO CHAPTER 1

Industry classification

I use the first ten sectors to construct the manufacturing sector and the last 13 to construct the service sector: 1. Manufacture of foods, beverage and tobacco, 2. Mining, 3. Textile, wearing apparel and leather products, 4. Other manufacture, 5. Production and supply of electric power, heat power and water, 6. Coking, gas and processing of petroleum, 7. Chemical industry, 8. Manufacture of nonmetallic mineral products, 9. Manufacture of machinery and equipment, 10. Construction, 11. Transport, Postal and Telecommunication services, 12. Total retail sales of consumer goods, 13. Wholesale and retail trades, 14. Hotels and catering services, 15. Tourism, 16. Financial Intermediation, 17. Education, 18. Science and technology, 19. Public health, 20. Social service, 21. Culture, 22. Physical education, 23. Public management, social security and others.[31]

Managerial share

To measure the managerial share in the production function, Quintin, 2008 first estimates the ratio of net income to value added in a sole proprietorship. The sole proprietors' net income attributable to managerial ability defines the managerial share. The rest of net income is attributed to sole proprietors' capital which defines the capital share. Quintin assumes the capital share is the same in a sole proprietorship as it is in large corporations and the government sector. I use

[31]Source: NBS

the data for self-employed individuals and household enterprises from the China Economic Census Yearbook 2004 to estimate the ratio of net income to value added for the service and manufacturing sectors. The value added is business receipts minus depreciation (5%) plus tax paid. The self-employment net income of owners is counted as operating revenue net of operating expenses (Chong-En and Zhenjie, 2010). I find the share of net income that remunerates managerial ability is 10% in the manufacturing sector and 15% in the service sector.