Market Structure and R&D Outsourcing

Zachary Cohle*

University of Florida

June 1, 2015

Abstract

This study proposes a simple model to describe innovative R&D location decisions by multinational firms. The model offers an explanation for the lack of R&D investment by multinational firms in developing regions. Using the threat of imitation, wage differences across regions, and economies of scope relating to R&D, I build a North-South model looking at a single firm's choice of research location in a number of different competitive environments. Overall, the model predicts weak IPR-protection in developing countries does not necessarily explain the lack of southern research. In some situations, a weakening of IPR-protection can even induce southern research. Harsh competition resulting from information leaks coupled with weak IPR-protection can explain much of the lack of innovative research investment in the developing world. My model also predicts smaller firms that require less innovative research will locate their R&D in the North. Medium sized firms will locate in both countries while the largest firms will locate research in just the South.

JEL Classification: F2, J3, L1, L2, O3

Keyworks: R&D, Innovation, IPR-Protection, Multinational, Employee Mobility

*Zachary Cohle: Department of Economics, University of Florida, Gainesville, FL 32611. Email: zhc17@ufl.edu; Tel: (352) 392-5805.

1 Introduction

In this paper, I explore innovative R&D (research & development) location decisions of firms across different countries using labor costs, intellectual property rights (IPR) protection, and the threat of imitation from a competing firm. My model explains the limited amount of multinational firm innovative R&D investment in the developing world. Using a North-South model, I examine a single firm, the Northern firm, and the firm's decision to locate innovative R&D tasks in either the North or the South in the context of a number of different competitive environments. The northern firm has a fixed number of research tasks that must be completed in order to develop a new, unique product. Researchers in the South are exactly as capable as researchers in the North; however, southern researchers earn a significantly lower wage. I use a partial equilibrium model in which the northern firm first chooses research locations to carry out its fixed amount of necessary research. A competing firm, the southern firm, has the chance to absorb some southern researchers in order to emulate the northern firm's product. After the fixed cost of entry has been paid, the northern firm chooses production decisions and either acts as a monopolist or competes against the southern firm.

As opposed to research designed at adapting products to different local markets (adaptive research), innovative research focuses on the invention on new products for sales in the global market. This new product development has largely been kept in the developed world. While two of the largest attractions for R&D offshoring in the developing world, India and China, remain largely sites for adaptive research, a few firms in the forefront of technology in their respective industries have started locating more advanced types of research in these regions (Lundin and Seger 2007, Walsh 2007, Atkinson 2007). For example, survey evidence from Sun, Du, and Huang (2006) found a majority of foreign R&D labs in Shanghai engage in adaptive research and development; however, GE is among the few multinationals conducting innovative research in the city. Demirbag and Glaister (2010) find evidence that more advanced research tasks tends to get outsourced to de-

veloped countries. Regions with higher knowledge profiles see more advanced research projects assigned to them when compared to clusters developing countries. The two largest attractions of R&D, India and China, are more likely to be assigned R&D tasks that fit into larger research projects started in the developed world. Barefoot (2012) notes that over 60% of outsourced R&D tasks out of the United States in 2010 went to technically advanced European countries. Only 0.6% of the money spent on outsourcing R&D went to India, one of the largest recipient of R&D outsourcing in the developing world.

In explaining the small amount of offshoring of innovative research to the developing world, this model distinguishes itself from past literature concerning IPR-protection through its treatment of innovative R&D as a fixed cost of entry. Similar to Melitz (2003), I model R&D as a necessary fixed cost of entry; however, the way in which the firm pays the fixed cost has real ramifications on production profits. Following Lai, Riezman, and Wang (2009), I include the notion of information leakages when outsourcing R&D. I use a probabilistic view of information leakage related to the intensity of the research done in the South. My model uses the notion of southern researchers defecting to competing firms as the channel of imitation. Researchers hired in the South can leave to either start their own firm or join a competing firm. Furthermore, the probability of southern researchers leaving as a team increases as the northern firm hires more southern labor. Although the model treats all research tasks the same, the greater number of researchers assigned in a region can act as a proxy for the complexity of the research project. The probability of the southern firm successfully copying the product and entering the market is modeled as a Tullock contest. In a Tullock contest, each player puts forth a certain amount of effort in order to attempt to win the contest. I introduce a proxy to player effort: the number of researchers employed by the northern firm in each area. Finally, I apply simple Cournot and Bertrand market structures in order to show that research decisions depend on the nature of competition and the market parameters.

The paper presents a number of findings. First, a firm's research needs will determine which

country or countries it locates. Small firms that require little research will locate in the North, while larger firms with large research needs will locate entirely in the South. Intuitively, the firms with a large need of research and development will have a large fixed cost in order to enter the market. These firms will be more willing to risk their product being imitated in order to avoid a high fixed cost of entry. Firm's with medium research needs locate in both countries. A main result of the model is the ambiguous effect of IPR-protection on R&D location decisions. Smaller firms, or firms that require less total R&D, respond to a weakening of southern IPR-protection by locating less research in the South. The increase in the probability of imitation caused by the IPR-protection reform induces the northern firm to avoid the risk of imitation by locating more research in the North. On the other hand, larger firms respond to a weakening of IPR-protection by shifting more research to the South. A firm with a high research and a large fixed cost of entry reacts to the decrease in expected revenue by further decreasing expected revenue in favor of decrease the fixed cost of entry. The final finding relates possible operating profit and research locations. A large difference between monopoly and duopoly profit induces the northern firm to locate more research tasks in the North. Imitation leads to a decrease in operating profit due to increased competition. When the decrease is large, the northern firm will find it more profitable to protect their patent than to cut costs in the R&D phase. Holding the penalty of imitation constant, a large wage gap between the North and South encourages southern research; however, the large wage gap might also imply a large penalty of imitation.

The paper is organized as follows. Section 2 summarizes related literature. Section 3 presents the assumptions, functional forms of the model, and the partial equilibrium solutions. Section 5 presents the results of the model. Section 6 introduces different market structures that can be applied to the model. Section 7 concludes the paper.

2 Related Literature

Endogenous growth literature typically assumes all innovative R&D is carried out in the North despite the growing trend of research being outsourced to the South. Ekholm and Hakkala (2007) have explored endogenous R&D locations; however, their analysis examined the knowledge profile of a country and not IPR-protection [1]. In their model, the capability of researchers in a country grows as more firms begin researching in that country. Based on the parameters values of the model (i.e. the degree of knowledge spillover), R&D locations may be concentrated in one country or spread out across both countries. Alacer and Zhao (2011) find that the leading firms in the high-tech industries tend to be the largest and have R&D labs spread throughout multiple locations and countries. Zhao (2006) also finds evidence of research tasks being split between developing and developed countries [2]. My model allows the northern firm to locate research tasks in different countries....

Ito and Wakasugi (2007) find that parent firms with high R&D spending have a tendency to decentralize their research tasks and thus do more research overseas. Other studies have shown that large research needs can result in more task being assigned to researchers in developing regions. Demirbag and Glaister (2010) find that as firms' research needs increase they start offshoring more in emerging regions. Using a unique measure of intra-industry offshoring constructed from measures of imports, home consumption, and input value, Canals and Sener (2014) also find firms in the low-tech industries have less offshoring when compared to their high-tech counterparts. This result is consistent with the the present model's prediction that firms with less need of research will

[1] Offshoring of innovative research in the 90s was largely driven by the desire to reduce costs and the need to increase the speed to markets; following this period, access to quality researchers becomes the driving factor (Lewin, Massini, and Peters (2009)). The knowledge profile seems to be less of a motivator as capable researchers can now be found in a number of emerging economies. For example, China's first year doctoral students have increased by a factor of six during that same time period (Lewin, Massini, and Peters (2009)).

[2] Zhao's analysis suggests that firms can work around weak IPR-protection through internal organization. In other words, the value of an information leak from a research lab in a host country is lessened by the technology's strong reliance on other technology or knowledge that a firm has gathered.

not offshore their research to the South. Hedge and Hicks (2007) also show high-tech industries engaging in the bulk of R&D outsourcing. My model also predicts the possibility of medium sized firms assigning some research tasks in both the North and the South. Consistent with the prediction of my paper, many studies have found a positive relationship between firm size and R&D. While some studies find that innovation increases more than proportionately with firm size, Symeonidis (1996) surveys all literature on the matter to conclude that the general consensus is that firm spending on R&D increases about proportionately with firm size given the firm has surpassed a certain threshold of size. My paper uses the required amount of R&D necessary for the invention of a new product as a proxy for firm size.

Moncada-Paterno-Castello et al. (2011), Demirbag and Glaister (2010), and Ito and Wakasugi (2007) present evidence of strong IPR-protection driving investment decisions for innovative R&D. Canals and Sener (2014) looks at firms in high-tech industries that require large amounts of initial research in order to create new products. Consistent with my model's prediction of only significantly larger firms even being influenced by IPR-protection changes, the authors find evidence of these firms expanding their offshoring activities after periods of IPR reform while low-tech sectors seemed unaffected by the strengthening of IPR-protection. Economic literature has long examined the effect of IPR-protection on innovation. Previous literature concerning endogenous growth theory has found conflicting effects of strong IPR-protection in developing countries. Tighter IPR-protection could lead to increases in innovation (Gustaffson and Segerstrom (2011), Branstetter et al (2007), Dinopoulos and Segerstrom (2010), Glass and Wu (2007), Gustaffson and Segerstrom (2011)) or decreases in the innovation rate (Dinopoulos and Segerstrom (2007), Helpman (1993)).

My model contributes to endogenous growth literature by introducing a new mechanism for imitation: employee mobility. Researchers in the South can take information gained while working on an innovation and produce their own version of the product to compete with the parent firm. Gambardella, Ganco, and Honore (2012) find a positive relationship between employee en-

trepreneurship and the value (as assessed by the firm and/or the employee) of an invention. More valuable patents will then be researched more so in the North to avoid employee mobility. A number of studies have also found evidence of information leakages through employee mobility [3]. In my model, the northern firm will attempt to hide a more valuable product, or one that has a high penalty of imitation, by locating more research in the North. The risk of exposing new product designs to future competition can be offset by the cost advantage of using southern labor. My model uses low wages to explain the allure of R&D location in developing countries as consistent with the findings of Lewin, Massini, and Peters (2009), Moncada-Paterno-Castello et al. (2011), and Demirbag and Glaister (2010). All of these authors note a difference in wage between the home and host country as a strong predictor of research location.

While my paper focuses on the outsourcing of research tasks, the model relates to outsourcing literature as a whole. Antras and Helpman (2004) use a North-South with endogenous inputs locations and outsourcing decisions. The authors find that industries that are input-intensive have firms only engaging in outsourcing in both countries while industries that are more based around northern headquarter services have input production from both outsourcing and vertical integration in both countries. While Antras and Helpman find productivity of the parent firm drives the decision to outsource in the South, my model introduces the notion of firm size as a factor involved in outsourcing choices. Grossman and Helpman (2002) also use a model with endogenous organization; however, firms must search for other firms who are willing to produce an intermediate input.

R&D games with spillovers and endogenous payoffs have been explored in the past (d'Aspremont and Jacquemin (1988), Chowdhury and Sheremeta (2010)). For example, Kamien, Muller, and Zang (1992) use a theoretical model with a firms spending on R&D spilling over into that firms

[3]Ganco (2013), using a researchers prior work at the firm as a proxy for the complexity internalized within the researcher, finds evidence suggesting researchers with a higher degree of internalized knowledge are more likely to begin their own firm. Knowledge complexity also seems to be positively associated with an entire team of researchers starting their own firm rather than individual entrepreneurship. Yang and Jiang (2007) provide a literature review of employee mobility in R&D outsourcing for emerging countries.

competitor. So, a firms R&D exploration may in fact make a tougher competitor for itself. Using an asymmetric Tullock lottery, my model builds in this externality by connecting the creation of a competing firm with the decision to employ researchers in the South; however, extra effort put forth by the northern firm in the contest to prevent imitation will directly decrease the effort of the competing firm in attempting to copy the product. This aspect of the model differs from the standard use of Tullock contests in R&D games [4].

3 The Model

Consider a world with two regions, North and South. Assume that Northern workers enjoy a higher wage than Southern workers. I focus on the research location decision of a single multinational firm (hereby referred to as the northern firm). This model is not concerned with this economy at large, only a select firm and its competitor. The timing structure is as follows: the northern firm discovers the total amount of research needed to make a new product, then chooses R^N and pays the fixed costs of entry, then a competing firm (referred to as the southern firm) enters the market with probability ϕ, and finally the northern firm produces and sells its product. This timing structure implies that the northern firm has two stages to make decisions. First, the firm chooses research levels across two countries. Then, after the market structure has been defined, the northern firm is faced with production related decisions in order to maximize operating profits. Since the northern firm observes the entry of its competitor, it has no need to maximize expected

[4] Skaperdas (1994) uses an axiomatic approach to provide support for using the CSF proposed by Tullock in a number of rent seeking contests. Tulluck contests have been applied to R&D races (Baye and Hoppe (2003)), elections (Snyder (1989)), and team sport leagues (Dietl et al (2011)). Specifically, Leininger (1993) examines the asymmetric Tullock lottery function similar to the one used in this paper. Leininger includes a scaling parameter on the effort of one player in order to reflect differential advantages. Baik (1994) and Fonseca (2009) explore the properties of asymmetric Tullock lotteries; however, few authors have looked at Tullock lotteries where a single player chooses both players effort levels. Jia, Skaperdas, and Viadya (2013) outline many difficulties in empirically examining a contest. Specifically, effort tends to be unobservable. Seeing as the actual researchers working on the project largely drive successful innovation, I model effort as the number of researchers in each region.

operating profits. Instead, the northern firm either acts as a monopoly (if no imitation occurs) or engages in competitive behavior (if imitation occurs and thus entry of the southern firm ensues). The northern firm maximizes expected profit by choosing R&D levels for each region. There are no fixed costs of production, only a fixed cost of entry. If imitation occurs, the northern firm must compete with the southern firm, yielding an operating profit of $\underline{\pi}$. Likewise, no southern entry allows the northern firm to act as a global monopoly and gain $\overline{\pi}$ from selling its product. Therefore, expected profits can be expressed as:

$$E(\pi) = (1 - \phi)\overline{\pi} + \phi\underline{\pi} - f_e \tag{1}$$

In order to be able to produce the product, the firm must first invest in innovative research and development. Research is composed of a variety of tasks, each requiring one unit of labor from either the North or the South. While one worker of either region produces one unit of labor, one unit of northern labor costs w^N, and one unit of southern labor costs w^S. If the firm engages in a large amount of R&D, it has less of a fixed cost of entry to pay. In other words, the firm can create a new product easier with a greater pool of R&D to use. So, before the firm is able to enter the market, it must first invest in R&D and combine the discoveries in research to create a new product to sell. Therefore, the entire cost of R&D and the creation of the new product can be seen as a fixed cost of entry for the firm[5]. The cost of labor can be found by multiplying the number of researchers in a region by that region's wage rate:

$$\begin{aligned} f_e &= w^N(R^N) + w^S(R^S) \qquad\qquad 0 < \alpha, b < 1 \\ &= w^N(R^N) + w^S(R^S) \end{aligned}$$

While the northern firm can cut costs by using southern labor for research, weak IPR-protection

[5]Linking R&D costs to the fixed cost of entry has been long established by previous international trade literature. For example, Melitz (2003) uses a model with a fixed cost a firm must pay in order to export. This fixed cost of exporting is explained as the cost of adaptive research in order to prepare the product to be sold in new markets.

in the South can lead to imitation from a southern competitor with a probability ϕ. The probability of imitation from an information leak is positively related to the amount of R&D done in the south [6]. More specifically, I define the probabilities as:

$$\phi = \theta \left(\frac{\zeta R^S}{R^N + \zeta R^S} \right) \qquad 0 < \zeta, \theta < 1 \tag{2}$$

$$1 - \phi = \frac{R^N + \zeta R^S (1 - \theta)}{R^N + \zeta R^S} \tag{3}$$

The exogenous parameter ζ measures IPR-protection in the South. The northern researchers can be seen as the effort extended by the northern firm to keep their patent upheld. Likewise, the southern researchers are the effort extended by the southern firm to successfully copy the new product [7]. A southern worker can leave to work at the southern firm after internalizing knowledge used in the creation of the new product; however, government IPR-protection barriers and the lack of other R&D knowledge prevent this worker from fully threatening the northern firm's claim on the patent. The IPR parameter also includes the complications associated with imitation. That is, there is a high fixed cost when emulating a product that includes both legal barriers and additional R&D to gather knowledge that was not gathered from southern researchers. So, the southern firm's effort, R^S, to copy the product is not weighted as much as the northern firm's efforts, R^N, to keep its patent. At $\zeta = 1$, the southern firm's effort is weighed equal to that of the northern firm. While ζ relates the effectiveness of the southern firm's effort in attempting to imitate the product, θ scales the contest to reflect any additional difficulties in imitating a product despite having access to the research gone into making the product. So, if all research is done by southern workers, and thus the southern researchers and southern firm have a reasonable claim to the patent, the probability of imitation will be equal to θ.

[6] The probability of imitation is based around the large amount of fixed costs that the southern firm must pay if it is not able to copy the product through mobile southern researchers. I assume that the southern firm will face sufficiently large costs to further research the product if the firm loses the imitation lottery. This additional fixed cost of entry is high enough to keep the firm out of the market. Also, I assume that successful imitation requires very little extra cost in order to enter the market. Thus, successful imitation leads to the entry of the southern firm.

[7] Although there has been some evidence to suggest that employee mobility and entrepreneurship is tied to individual performance (Carnahan, Agarwal, Campbell 2012), I treat each southern researcher as homogenous in their threat of leaving to bring their knowledge to a competing firm.

At $\theta = 0$, copying the product is impossible and the southern firm will not be able to enter the market. For example, the internal knowledge that the northern firm keeps in their headquarters may be fundamental to the creation of the product. Despite the southern firm having access to all the knowledge created in the South, it will not be able to combine the knowledge into an actual product. When $\theta = 1$, a Tullock lottery between the northern and southern firms solely determines whether imitation occurs. Although the probability function in this model draws from Tullock's proposed success function, the northern firm sets both effort levels [8]. To simplify the model, I set $\theta = 1$ [9]. The parameter ζ becomes the sole measure of IPR-protection in the South. A ζ near zero indicates strong southern IPR-protection, while a ζ near 1 indicates weak IPR-protection. If all research is done in the South, imitation followed by competition will occur with absolute certainty regardless the strength of the South's IPR-protection laws. As ζ increases, the probability of imitation increases. The total amount of research carried out is fixed by some production function for the creation of new products. Consider the following Cobb-Douglas function:

$$Y = b_1 R^{1-\alpha_1} \tag{4}$$

To produce one new product, or $Y = 1$, the northern firm needs to employ some number of total researchers such that the production function can be satisfied. I solve for the total research level that will allow for the creation of a new product:

$$\overline{R} = (\frac{1}{b_1})^{\frac{1}{1-\alpha_1}} \tag{5}$$

The following analysis will just use $\overline{R}$ as a fixed parameter. Given this fixed total research

[8] Because only one player sets both effort levels, the probability function used here is incompatible with other forms of the Tullock contest probability functions. For example, second order conditions do not hold when a power Tullock CSF is used.

[9] In general, θ adds a certain amount of realism to the model in providing an additional barrier to imitation when all research is carried out in the South. When $\theta = 1$ however, model's results remain relatively unchanged. I explore the case where $0 < \theta < 1$ in the Appendix.

level, the northern firm will choose the number of researchers in both regions by merely setting the value in one region. That is, R^S can be expressed in terms of the fixed total research value and northern research:

$$R^S = \overline{R} - R^N \tag{6}$$

Given these probabilities and total research levels, expected profits can be defined:

$$E(\pi) = \frac{R^N}{R^N + \zeta R^S}\overline{\pi} - \frac{\zeta R^S}{R^N + \zeta R^S}\underline{\pi} - w^N(R^N) - w^S(R^S)$$

$$= \left(\frac{R^N}{R^N(1-\zeta) + \zeta\overline{R}}\right)[\overline{\pi} - \underline{\pi}] + \underline{\pi} - w^N(R^N) - w^S(\overline{R} - R^N) \tag{7}$$

The actual values of $\overline{\pi}$ and $\underline{\pi}$ depend on the market structure and the nature of competition between the northern firm and the southern firm. Since the northern firm observes the southern firm's entrance outcome before making production decisions, the production decisions does not depend on the R&D choices. First, I will solve for R^N in terms of a generic $\overline{\pi}$ and $\underline{\pi}$ values. Then, using a linear demand, I will apply different competitive structures to see how production specific factors influence the R&D choices.

3.1 Equilibrium

The northern firm solves the following maximization problem:

$$\max_{R^N} E(\pi)$$

The firm will not hire more researchers than is necessary to complete the innovation. Likewise, the firm cannot hire a negative amount of researchers. So, R^N is bounded by 0 and $\overline{R}$. In order

to guarantee concavity, a number of assumptions are needed. First, I let $\overline{\pi} > \underline{\pi}$. Monopoly profit, $\overline{\pi}$, must be greater than duopoly profit, $\underline{\pi}$, as is standard in economic literature. Next, I assume $w^N > w^S$. The wage paid to northern workers in the developed world is greater than the wage paid to similar workers in the developing world. Finally, I assume $0 < \zeta < 1$. As seen before, shows that the South has imperfect IPR-protection. Due to the many challenges of imitation, he effort by southern researchers to steal and emulate the innovation is inherently less effectively than the northern firms effort to keep the innovation. Given these assumptions hold, a first order condition yield will yield a maximum value of northern research. For the remainder of the discussion, I assume that these assumptions do in fact hold. [10]

Proposition 1. *The profit function (7) is concave for* $R^N \in \{0, \overline{R}\}$.

Proposition 1 implies that first order conditions yields a value of R^N that maximizes profit function (7) if this value exists between 0 and $\overline{R}$. If in fact the FOC does not yield a value within these bounds, then optimal northern research amount is located at one of these bounds depending on whether the profit function strictly increases or decreases with R^N between the range of interest, 0 and $\overline{R}$. The type of solution, interior or corner, can be determined by looking at the relationship between total research, the penalty of imitation, IPR-protection, and the wage gap [11]. In order to better discuss the comparative statics of this model, I focus on three assumptions on parameter values:

Case 1: The firm locates all research in the North

Case 2: The firm locates research in both the North and the South

Case 3: The firm locates all research in the South

[10] The second derivative of profit function (7) is equal to $\frac{\partial^2 \pi}{\partial R^{N2}} = \frac{-(1-\zeta)\zeta\overline{R}[\overline{\pi}-\underline{\pi}]}{(R^N(1-\zeta)+\zeta\overline{R})^3}$. It is trivial to show that the profit function is concave given the assumptions on the parameter values and the bounds on R^N.

[11] These parameter relationships are explored in Appendix C.

Taking the FOC and rearranging yields the optimal northern research level [12]:

$$R^{N*} = (\frac{1}{1-\zeta})\left(\frac{[\overline{\pi}-\underline{\pi}]\zeta\overline{R}}{w^N - w^S}\right)^{\frac{1}{2}} - (\frac{\zeta}{1-\zeta})\overline{R}$$

Taking the value for R^{N*} along with equation (6) and the bounds on the northern research levels yields a unique solution for the optimal northern and southern research levels:

$$R^N = \begin{cases} \overline{R} & \text{if} \quad \overline{R} < R^{N*} \\ (\frac{1}{1-\zeta})\left(\frac{[\overline{\pi}-\underline{\pi}]\zeta\overline{R}}{w^N - w^S}\right)^{\frac{1}{2}} - (\frac{\zeta}{1-\zeta})\overline{R} & \text{if} \quad 0 < R^{N*} < \overline{R} \\ 0 & \text{if} \quad R^{N*} < 0 \end{cases} \tag{8}$$

$$R^S = \begin{cases} 0 & \text{if} \quad \overline{R} < R^{N*} \\ (\frac{1}{1-\zeta})\overline{R} - (\frac{1}{1-\zeta})\left(\frac{[\overline{\pi}-\underline{\pi}]\zeta\overline{R}}{w^N - w^S}\right)^{\frac{1}{2}} & \text{if} \quad 0 < R^{N*} < \overline{R} \\ \overline{R} & \text{if} \quad R^{N*} < 0 \end{cases} \tag{9}$$

Equations (8) and (9) show the optimal northern and southern research levels for Case 1, Case 2, and Case 3, respectively. The wage gap, the penalty of imitation, IPR-protection, and the total amount of research needed to innovate affect the optimal level of northern researchers employed. Initial inspection reveals that the amount of northern researchers increases with the penalty of imitation. The wage gap, on the other hand, seems to have a negative relationship with northern labor; however, the wages may also relate to monopoly and duopoly profit. The IPR-protection parameter and the total research seem to have an ambiguous effects. Note that in Case 2, the northern research level increases only for very small values of $\overline{R}$ [13] Northern research will then steadily decrease with $\overline{R}$ until the northern firm moves entirely to the South. When setting the

[12] FOCs actually yield two solutions for R^N; however, the unreported value of northern researchers is a negative value and exists on the portion of the profit function that is convex. This unreported solution is thus a minimum.

[13] Specifically for $\overline{R} < (\frac{1}{4})\ \frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N - w^S)}$.

optimal research levels, the northern firm thereby sets the probability of imitation in equilibrium:

$$\phi = \begin{cases} 0 & \text{if} \quad \overline{R} < R^{N*} \\ \left(\frac{1}{1-\zeta}\right)\left(\frac{\zeta\overline{R}(w^N - w^S)}{[\overline{\pi} - \underline{\pi}]}\right)^{\frac{1}{2}} - \left(\frac{\zeta}{1-\zeta}\right) & \text{if} \quad 0 < R^{N*} < \overline{R} \\ 1 & \text{if} \quad R^{N*} < 0 \end{cases} \tag{10}$$

As expected, the probability of imitation weakly decreases as the penalty of imitation increases. The northern firm will attempt to prevent employees from leaving the firm and imitating valuable innovations by locating more research in the North and thus lowering the probability of imitation. Again, the IPR parameter has an ambiguous effect. The probability also weakly increases as total research increases. This result seems to conflict with the relationship between R^N and $\overline{R}$. For low values of $\overline{R}$ and a weak IPR environment, northern research can increase as total research increases while the probability of imitation also increases. In this situation, the firm locates only a portion of the new required research in the North. The rest of the needed research is contracted to the South, which continues to increase the probability of imitation. In fact, the share of northern labor to total labor weakly decreases with total required labor. Figure 1 shows the ratio of northern research to total research and the ratio of southern research to total research as functions of $\overline{R}$. The share of northern research will be greater than the share of southern research for small values of $\overline{R}$.

[INSERT FIGURE 1 HERE]

When the northern firm has a small level of needed research, the firm locates entirely in the north. As $\overline{R}$ increases, the northern firm will shift more resources to the South. After a certain point, the northern firm will only use southern research. A large amount of research required to create a new product means the fixed cost of entry will be large. The only way in which entry would be feasible is if the northern firm conducted the research in the South. A low value of total

research means the cost of research will be small. Note that a high $\overline{R}$ coupled with a low duopoly profit will prevent the northern firm from entering the market completely. Increasing the value of total research will increase the costs of research and thus the fixed cost the firm must pay in order to enter the market with a new product. The firm attempts to lower this fixed cost by locating more research in the South, where labor is cheap. Figure 1 shows the interval of total research in which the firm will locate in both countries. Formally, that interval is:

$$\frac{\zeta[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} < \overline{R} < \frac{[\overline{\pi} - \underline{\pi}]}{\zeta(w^N - w^S)} \tag{11}$$

When $\overline{R}$ falls in the interval expressed in Condition (11), the northern firm will locate research in both the North and the South. Notice that for $0 < \zeta < 1$, the left hand side of this inequality is less than the right hand side. The plausibility of this condition is then based on the relationship between the demand specific parameters, production decisions, degree of competition, wage differential, southern IPR-protection, and the level of total research. Note that strengthening southern IPR-protection (lower ζ) will lead to a decrease in the left hand side and an increase in the right hand side. So, a strong IPR-protection environment in the South will facilitate the existence of southern research. In contrast, the penalty of imitation interacts with the left and right hand side in the same way. An increase in the penalty of imitation shifts the interval expressed in Condition (11) to the right; therefore, the northern firm may be induced away from southern research as the penalty of imitation increases dramatically. The difference in wages in the North and the South has a complicated effect. As with the penalty of imitation, the wage differential acts directly on the left and right hand side in the same direction; however, wages also have an indirect effect. The profit collected in the production phase depends on the wages as well.

4 Results

4.1 Total Needed Research's Effect on R&D Locations

Research location decisions will be a factor of the total amount of research necessary to make the new innovation. As seen in Figure 1, firms with the smallest small research needs will locate entirely in the South while firms with the largest research needs will locate entirely in the North. Firms with medium research needs will locate in both countries:

Result 1. *Large values of initial total research, specifically* $\overline{R} \geq \frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N-w^S)}$*, induce the northern firm to locate research only in the South. Low values of initial total research,* $\overline{R} \leq \frac{\zeta[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)}$*, induces the northern firm to locate all research in the North. The northern firm locates in both countries for medium values of initial research,* $\frac{\zeta[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)} < \overline{R} < \frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N-w^S)}$.

Result 1 relates the extra cost in research in locating in the North over the South to the penalty of imitation. The IPR-protection parameter, ζ, weighs the penalty of imitation. That is, the cost of researching in only the North does not need to exceed the full penalty of imitation for the northern firm to start splitting research tasks between nations. Likewise, the cost penalty of researching in only the North must be significantly greater than the penalty of imitation in order for the northern firm to find locating in only the South profitable. The stronger the IPR-protection environment in the South, the greater the cost penalty of researching in only the North must be for the northern firm to be willing to locate all research in the South. Again, the values of initial research need to create a new product can be seen as a proxy for firm size. Larger firms will have the resources to secure initial funding for R&D for advanced projects that require large amounts of research. While the relationship does not always hold, the correlation between the two factors generally implies that larger firms will be the ones investing in the research projects that require a large amount of research tasks to be completed. These large firms are also more likely to already have the infrastructure to both facilitate the coordination of research across multiple locations and properly

market and sell the new product. When looking across different industries, firms in high-tech industries will have large values of $\overline{R}$ while the opposite is true for firms in low-tech industries.

4.2 IPR-Protection Effects on R&D

There are two main drivers, after total needed research, of the northern firm's actions for a given market structure: wage rates and IPR-protection. The use of labor in both the production and research stages complicate the interpretation of wage effects on the system. Although the wage in each country factors into both the production decisions and the R&D decisions, IPR-protection only affects research choices. IPR-protection has a dual effect on the optimal research levels. From Equation (8), a strengthening of southern IPR-protection (a decrease in ζ) can affect R^N both negatively and positively. That is, the increase in expected profit caused by changing IPR regime will prompt the northern firm to reallocate some resources into the less expensive South; however, a high monopoly profit may cause the firm to increase the probability of gaining that profit even more so to offset the IPR-protection change. The change will depend on whether the expected profit is increased more by lowering the fixed costs or by increasing the chance to gain the monopoly profit. Again, the amount of total research needed plays a role in determining how the northern firm reacts to IPR changes:

Result 2. *Weakening southern IPR-protection will have an ambiguous effect on R^N and R^S. Specifically, a weakening of southern IPR-protection, or increasing ζ, will result in an decrease in R^N iff $\left(\frac{1+\zeta}{2}\right)^2 \frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N-w^S)} < \overline{R} < \frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N-w^S)}$. Otherwise, $\frac{\partial R^N}{\partial \zeta} \geq 0$ and $\frac{\partial R^S}{\partial \zeta} \leq 0$.*

When an interior solution does not exist, IPR-protection has no influence on the northern firm's research location decision. The probability of imitation in these situations does not relate to IPR-protection. If the northern firm locates research and production in only the North, the southern firm will never have a chance to copy information and produce their own product in this model.

So, the level of IPR-protection in the South should have no effect on the northern firm's northern institutions. Likewise, locating all research in the South results in imitation with 100% certainty. The level of IPR-protection will not factor into the northern firm's comparison between the two possible expected profits.

In Case 2, on the other hand, a weakening of IPR-protection in the South could cause the northern firm to either increase northern research, as one would expect, or decrease northern research in order to increase expected operating profits even more so. In line with previous literature, the model does not predict a definitive effect of IPR-protection on innovation. When a relatively small amount of research is needed, the northern firm reacts to an increase in ζ by increasing northern research and decreasing southern research. The low levels of required research indicate a low fixed cost of entry. The decrease in the expected operating profit caused by the worsening of the IPR environment would then cause the northern firm to shift more resources into the North as the marginal change in the expected operating profit will outweigh the marginal change in fixed costs. Figure 2 shows the result of a weakening of IPR-protection resulting in a decrease in southern labor. After the weakening of IPR-protection, the firm moves from point A to point B. For higher values of total research, the fixed cost of entry will be high. A weakening of IPR-protection yields a decrease in expected revenue, which the northern firm then recoups by decreasing the already high fixed costs of entry. So, the firm then responds to the weakening of IPR-protection by, counter intuitively, increasing southern researchers. Figure 3 shows this case. The interval in which the firm exists in Case 2 shrinks as IPR-protection weakens, meaning that small firms who found had research in the South might be moved entirely into the North by a weakening of IPR-protection.

[INSERT FIGURE 2 HERE]

[INSERT FIGURE 3 HERE]

The probability of imitation will increase when ζ increases iff $\left(\frac{2}{1+\zeta}\right)^2 \frac{\zeta[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)} < \overline{R}$. This minimum value is also the point at which the southern research share starts to overtake the northern research share as seen in Figure 1. Since this point is less than $\left(\frac{1+\zeta}{2}\right)^2 \frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N-w^S)}$, there will be a region in which the northern firm increases northern research in the face of a weakening of IPR-protection, but the probability of imitation increases still due to the change in ζ.

4.3 Market Structure and Wage Effects on R&D

The structure of the competitive market will dictate a number of decisions the northern firm faces. The values of each profit level are not of interest at this time. The model is built around the difference between monopoly profits and duopoly profits, or the penalty of imitation. The value of this difference in relation to the other parameters of the model will dictate the northern firm's choices.

Result 3. *An increase in the difference between monopoly profit and duopoly profit weakly increases in R^N, a decrease in R^S. In general, an increase in the penalty of imitation deters investment in southern research.*

Result 3 implies that competitive structures that have higher duopoly profits will cause the northern firm to locate more research in the South. Given the penalty of imitation is small, the northern firm will take advantage of the cost difference between southern research and northern research. On the other hand, a large penalty of competition will cause the firm to locate in the North to be able to obtain a monopoly profit and capture the entire market. Likewise, when the northern firm prefers to locate in both countries, an increase in the penalty of imitation will induce the northern firm to locate more research in the North. This change then decreases probability of

imitation and increases the probability of the northern firm being a monopoly in the production stage.

[INSERT FIGURE 4 HERE]

Figure 4 graphically shows the effect of an increase in the penalty of imitation on the optimal R^N and R^S. Notice that a substantial increase in the penalty of imitation results in the northern firm not locating in the South at all. Also, Condition (11) does not enlarge or shrink as the penalty of imitation changes. Instead, the interval shifts right with an increase in the penalty of imitation and shifts left with a decrease. So, harsh competition discourages investment in southern research. The difference between the monopoly and duopoly profit levels depends on the nature of competition in the duopoly phase. Monopoly profits will remain constant across all duopoly structures. A duopoly profit of zero will result in the northern firm locating all research in the north. Locating in the South in this situation would result in no operating profits whatsoever to help pay off the fixed cost of entry.

Holding the monopoly profit and duopoly profit equal, a large wage gap induces the northern firm to invest heavily in southern research, which is expected. Relatively cheap labor in the South will help drive southern research investment. An increase in the wage gap will cause both the left hand side and right hand side of Condition (11) to decrease. An increase in the wage gap may push a firm from locating entirely in the North to locating in both countries. A large wage gap induces the northern firm to invest heavily in southern research, which is expected. Relatively cheap labor in the South will help drive southern research investment.

Result 4. *Holding all else equal, a large wage gap will weakly increase* R^N.

The wage rate my in fact be related to the wage of the workers used to produce the good. So, an exogenous rise in the wages of researchers may also be reflected in the wage of laborers. In this

model, I assume that researchers are paid the exact same wage rate as laborers. Therefore, a large wage gap also means that the southern firm has a large cost advantage during the production phase, hence the penalty of imitation will be high. A large wage gap then is not sufficient for southern research to take place. The probability of imitation increases with a large wage gap, meaning the northern firm would both reduce fixed cost by putting more research in the South and increase the probability of collecting the monopoly profit. The monopoly and duopoly profits will in fact change with changes in the wage rates. So, the effect of a wage change is unclear without defining a market structure first. Overall, the effect of a wage changes on research allocation is ambiguous.

5 Market Structure Effects

The penalty of imitation will depend heavily on the market structure of the final goods market. When there is no information leak, the northern firm is the only firm on the market and acts as a monopoly. When an outside southern firm is able to imitate, the northern firm must compete with this firm [14]. The operating profit for the northern firm with the presence of the southern firm will depend on how the two firms compete for customers in their industry. Consider the possibility of only the northern firm and the southern firm (producing q_1 and q_2, respectively) selling their good to a continuum of homogeneous consumers. Consumers purchase goods from this monopolistic sector and an outside good, q_0, from a competitive sector. Consumers choose q_1 and q_2 with the utility function,

$$U(q_0, q_1, q_2) = q_0 + A(q_1 + q_2) - \frac{1}{2}(\beta_1 q_1^2 + 2\gamma q_1 q_2 + \beta_2 q_2^2) \tag{12}$$

[14]The southern firm, like the northern firm, has no fixed cost of production. Furthermore, the fixed cost of entry to the southern firm would be related to the cost of stealing information from the northern firm. The other aspect of the southern firm's fixed cost of entry is the additional research needed to create the product. It is possible that even after an information leak, the additional fixed cost of entry is too high for the southern firm to enter the market.

Let A_i and β_i be postive for i=1,2. Also, assume $\beta_1\beta_2 > \gamma^2$ and $\beta_i > \gamma$ for $\forall i$. The parameter γ measures the degree of substitutability between the two products. I assume that the two products are perfect substitutes [15]. Assume that the southern firm exclusively uses southern labor in production while the northern firm uses only northern labor. Also, it takes on worker to produce one unit of the final good. Assume that $A > w^N$. In other words, the market must be sufficiently large in order for the firm to be able to find it profitable to produce. When the southern firm does not enter the market, the northern firm gathers a monopoly profit of:

$$\overline{\pi} = \frac{(A - w^N)^2}{4\beta_1} \tag{13}$$

As seen above, the monopoly profit increases with market size, or an increase in A. The more consumers buying the product, the higher profits the northern firm will make. β_1 relates the price and quantity of a good for consumers. An increase in β_1 decreases the consumers quantity demanded for a given price. The price set by the monopolist is unaffected by β_1; however, the quantity sold is inversely related to the parameter. Note that the monopoly profit will not change regardless of the market structure, with the exception of β_1 which will change when the products produced by both firms are undifferentiated. Sections 5.1 and 5.2 explore this case.

5.1 Betrand with Undifferentiated Products

In Bertrand competition, firms compete in price space. In order to have undifferentiated products, let $\gamma = \beta_1 = \beta_2 = \beta$. With undifferentiated products, the firm that sets the lowest price will

[15] I also explored markets with slightly differentiated products. The degree of substitutability becomes a key factor in the comparative statics of any market parameter. For example, the inclusion of differentiated products makes duopoly profit more sensitive to wage and total research changes than monopoly profit given small wage differential.

gain the entire market. So, demand for the northern firm can be re-specified as:

$$q_1(p_1, p_2) = \begin{cases} \frac{Q(p_1)}{2} & \text{if } p_1 = p_2 \\ Q(p_1) & \text{if } p_1 < p_2 \\ 0 & \text{if } p_1 > p_2 \end{cases}$$

Given $w^N > w^S$, the southern firm will be able to set a price at $(w^N - \epsilon)$, where $\epsilon > 0$ is a small number, and thereby price the northern firm out of the market. The northern firm would earn negative a profit if it produced at this price and zero profit if it does not produce. Therefore, $\underline{\pi} = 0$. [16]

5.2 Cournot with Undifferentiated Products

Firms compete in quantity space in Cournot environments, so both firms maximize their profits by choosing q_i. Again, let $\gamma = \beta_1 = \beta_2 = \beta$. Unlike the monopoly profit, $\underline{\pi}$ will depend on the southern firm's marginal cost, or w^S. Using this inverse demand, the northern firm's profit under this competitive framework are:

$$\underline{\pi} = \frac{(A - 2w^N + w^S)^2}{9\beta} \tag{14}$$

As with the monopoly profits, the profit for the northern firm under competition is positively related to market size. Northern duopoly profits are also related to positively related to w^S. So, as the marginal cost of the competitor increases, the northern firm is able to gain more market share and thus achieve higher profits. Furthermore, $\underline{\pi}$ decreases as β increases in a similar manner as monopoly profits. An increase in the northern firm's marginal cost, w^N will, expectedly, decrease

[16] If the northern firm was able to produce in the south, both firms have the same marginal cost and would thus be unable to drive either out of the market. The firms would set price equal to marginal cost, w^S, to prevent the other firm from undercutting their price and gaining the entire market. So, the firms split the market but make no profit on every unit sold, and $\underline{\pi} = 0$.

$\underline{\pi}$; however, the decrease in monopoly profits for the same increase in w^N will be larger. Also, note that the monopoly profits are higher than the profits under competition, which is expected.

5.3 Wage and Market Size Effects on R&D

Market size only factors into the northern firm's decision through monopoly and duopoly profits. So, the change in the difference of these two profit levels due to a change in market size will dictate the change in the northern firm's research decision.

Proposition 2. *In market structures with undifferentiated products, an increase in the market size will increase the difference between the monopoly and duopoly profits.*

Using Proposition 2, an increase in the market size will help facilitate the northern firm locating more, if not all, research in the North. A larger market means more customers. The monopoly can gain all of these customers while the duopoly must split the new consumers with the southern firm. So, both profit levels increase; however, the monopoly profit increases more than the duopoly profit. The effect of a market change on research levels is then the same Result 3.

Proposition 3. *In market structures with undifferentiated products and for firms in Case 2, a rise in the northern wage rate will decrease R^N and increase R^S. A rise in the southern wage rate will have an ambiguous effect in the Cournot case. In the Betrand case, an increase in w^S increases northern research and decreases southern research.*

For both Betrand and Cournot environments with undifferentiated products, an increase in the northern wage rate decreases the penalty of imitation. The higher cost of northern research also makes southern researchers more attractive to the northern firm. Since the penalty of imitation is lowered, the northern firm is less concerned with deflating the probability of imitation. Therefore, the northern firm contracts more research in the South in order to take advantage of the relative decrease in the price of southern labor. When w^S increases in the Bertrand case, the difference in possible profits for the northern firm remains unchanged. Again, the northern firm is priced out of

the market as long as the southern wage is lower than the northern wage. In the Cournot case, the difference between profits shrinks as the southern wage increases. The southern firm's marginal cost rises, making them a less fierce competitor to the northern firm. So, the northern firm may increase northern research in the face of this change in order to increase the probability of gaining the monopoly profit. If the difference between possible profits is small enough as a result of the change in w^S, the northern firm will find its current amount of northern researchers to be excessive and shift resources to the South. Since the penalty of imitation decreases, the appeal of northern researchers decreases greatly. Finally, when the northern locates all research in the North, the southern wage will not affect expected profit. The northern firm employs no southern labor and imitation will not occur; therefore, the southern wage rate will not affect any of the firm's decisions.

Proposition 4. *For Betrand competition with undifferentiated products, the northern firm will never locate research only in the South.*

Proposition 5. *For markets with differentiated products and Cournot markets with undifferentiated products, the northern firm will locate all research in either country or locate in both the North and the South.*

The Betrand market structure with undifferentiated products case gives the maximum difference between monopoly and duopoly profits. When the northern firm locates solely in the South, they earn no operating profit. Therefore, the total profit function will only consist of the fixed cost of entry. The northern firm would be earning a negative profit and thus be worse off than staying out of the market completely. If the probability of imitation is low enough the northern firm could still locate some research in the South. Note that the other market structures see the northern firm earning a positive duopoly profit, meaning locating entirely in the South is still an option.

6 Conclusion

This model's main purpose is to explain the lack of southern innovative research in the face of a low southern wage and capable researchers. Innovative research in the developing world is discouraged by the harsh penalties of product imitation. If imitation leads to the northern firm being driven out of the market completely by firms who did not have to invest in costly research to invent a new product, then the northern firm will only locate research in the North. My model predicts that a medium sized firm can benefit from splitting research tasks between both nations. This prediction matches the growing trend in the real world of conducting research in both low income and high-income nations. The model also predicts smaller firms will be less likely to outsource innovation while larger firms will outsource all innovation.

In explaining the lack of innovative R&D done in the South, IPR-protection plays a distinct but somewhat ambiguous role. Again, IPR-protection does not factor into the northern firm's choices when it locates all research within one country. In the case that the northern firm locates in both countries, IPR-protection has an ambiguous role. While strengthening IPR-protection in the South could result in the northern firm moving research to the South, the increased probability of gaining a monopoly profit could cause the northern firm to locate even more research in the north to further increase this probability. In this case, the northern firm willingly pays a higher cost of entry in order to increase expected operating profits. My model also explains the lack of southern research as a result of wage differences. In the model, wages factor into the production process and the pre-production process (or the research phase). A high enough northern wage relative to the southern wage causes the northern firm to locate a majority, if not all, research in the South; however, harsh enough competition in the South will prevent the northern firm from locating in the South, regardless of the size of the wage gap.

The growing value of having research tasks in both countries should be kept in mind when

policy makers begin thinking about intellectual property rights reform. This paper provides the framework for a number of future research projects addressing a variety of issues. While this model deals with a single northern firm and its southern competitor, it does not look at the economy as a whole; the results of this paper can be applied to multiple firms in isolation. Furthermore, the interplay between research labs and production sites in context to information leakage has not been explored with this model and would be a possible avenue for extensions of this paper. That is, given the colocation of a production site and a research site, the probability of an information leak would be higher than if the two sites were located in different regions with different IPR laws. While this model only presents the northern firm's research choices, including a look at the southern firm's fixed cost of entry could be a possible addition as well. That is, by performing only a few R&D task in the South, the northern firm increases the fixed cost of entry of the southern firm. After absorbing information from the southern research sites, the southern firm would still need to do additional research in order to create the product. By having integral research done in strong IPR countries, the northern firm can severely limit the damage of an information leak. My analysis treats all research tasks the same; however, some tasks are more key to the functionality of the overall product than others. The northern firm has the ability to lessen the value of some research tasks by having it rely heavily on other tasks not known to the southern researchers.

While the model presented above shows the effects of different market structures on research decisions, each market structure contains only two firms at most in the market with undifferentiated products. An information leak that leads to perfect competition would yield similar results to Bertrand competition with undifferentiated products. If the information leak leads to only a few firms entering the market with differentiated products, the degree of substitution between the products produced by the firm will dictate the northern firms response to competition. Finally, this model could be empirically modeled. Data measuring IPR-protection strength exist along with some data on research project spending (although this data may be tough to find for multinationals). Similar to Branstetter et al (2007), large moments of IPR-reform within a country can be

used empirically in order to see the response to firms. As predicted in this model, the larger firms should actually be drawn away from locating innovation within a country when IPR-protection is strengthened. My model also suggests an empirically observable analogue to effort: researchers. In conclusion, my model provides a springboard for a number of other inquires into R&D across nations.

7 Appendix

A Equilibrium Profit

With the calculated R^N, R^S, and probability of imitation, the three possible expected profit levels are:

$$E(\pi)^N = \overline{\pi} - w^N \overline{R} \tag{15}$$

$$E(\pi) = (\frac{1}{1-\zeta})[\overline{\pi} - \underline{\pi}] - (\frac{2}{1-\zeta})(\zeta \overline{R}(w^N - w^S)[\overline{\pi} - \underline{\pi}])^{\frac{1}{2}} + (\frac{\zeta}{1-\zeta})\overline{R}(w^N - w^S)$$

$$+\underline{\pi} - w^S \overline{R} \tag{16}$$

$$E(\pi)^S = \underline{\pi} - w^S \overline{R} \tag{17}$$

Equation (15) represents the profit level of a Case 1 firm. Equation (16) is the profit of a firm in Case 2, and a firm in Case 3 have a profit as shown in equation (17). While staying out of the

market completely is a viable option, it remains relatively uninteresting. The northern firm will only choose to not enter the market when the expected profit is always negative. This possibility depends on the parameters of the model and market structure. I assume away this case and only focus on the two corner cases and the one interior case.

The first thing to note about the above expected profit is that southern IPR-protection is not included. When the northern firm locates all research in the North, the probability of southern imitation is zero. Likewise, imitation occurs with certainty when the northern firm locates all research in the South. The fixed cost of entry is solely the total research multiplied by the wage of the country in which the northern firm locates research and the cost of development, which is the same in both expected profit functions. Also, there is an additional unit of northern wage paid to the headquarter labor. This cost also exists in both expected profit functions. Finally, the total research level, which the firm does not control, has an ambiguous effect on both expected profits. While an increase in total research will increase the cost the northern firm pays for research, the cost of development shrinks. The change in expected profit then depends on which effect dominates.

B Including θ as an IPR-Protection Parameter

Let $0 < \theta < 1$. This yields a new expected profit function:

$$E(\pi) = \frac{R^N + \zeta R^S(1-\theta)}{R^N + \zeta R^S}\overline{\pi} - \frac{\zeta\theta R^S}{R^N + \zeta R^S}\underline{\pi} - b[R^N + R^S]^{-\alpha} - w^N(R^N) - w^S(R^S)$$

$$= \left(\frac{R^N + \zeta R^S(1-\theta)}{R^N + \zeta R^S}\right)[\overline{\pi} - \underline{\pi}] + \underline{\pi} - b[\overline{R}]^{-\alpha} - w^N(R^N) - w^S(\overline{R} - R^N) \tag{18}$$

Maximizing Equation (18) by choosing R^N yields:

$$R^N = (\frac{1}{1-\zeta})\left(\frac{\theta[\overline{\pi}-\underline{\pi}]\zeta\overline{R}}{w^N - w^S}\right)^{\frac{1}{2}} - (\frac{\zeta}{1-\zeta})\overline{R} \tag{19}$$

While θ does decrease the value R^N at any given $\overline{R}$, the inclusion of the IPR-protection parameter does not affect the directional response of R^N to any other given parameter; however, with $\theta < 1$, the magnitude of any comparative statics will change. Since θ enters the Equation (19) in only one place, the parameter can be absorbed into the penalty of imitation variable. So, the inclusion of the variable will be akin to lowering the penalty of imitation. Thus, the interval of possible interior solutions shifts:

$$\frac{\zeta\theta[\overline{\pi}-\underline{\pi}]}{(w^N - w^S)} < \overline{R} < \frac{\theta[\overline{\pi}-\underline{\pi}]}{\zeta(w^N - w^S)} \tag{20}$$

From Condition (20), including the extra IPR-parameter, θ, shifts the interval to the left. Smaller firms that located research only in the North will therefore be able to locate some research in the South if the IPR-protection strengthens. Also, note that as θ increases, R^N decreases in Equation (19). While θ does not greatly impact the comparative statics of this model, the profit function when the northern firm locates research solely in the South:

$$E(\pi)^S = (1-\theta)[\overline{\pi}-\underline{\pi}] + \underline{\pi} - b\overline{R}^{-\alpha} - w^S\overline{R} \tag{21}$$

Compared with Equation (17), the profit function in Equation (21) has an extra term reflecting the new possibility of imitation not occurring. The profit function for the opposite case, when the northern firm locates in the North, remains unchanged. So, θ builds in the realism that imitation is not guaranteed, the model does little to change the main results of this paper. This extra IPR parameter will change some of the results when different market structures are applied to the model. For example, even the harshest competitive environments could now see a northern firm with a high research need locating research fully in the South.

C Proof of Interior Solution Parameter Conditions

Taking the derivative of profit function (7) with respect to R^N yields:

$$\frac{\partial \pi}{\partial R^N} = \frac{\zeta \overline{R}[\overline{\pi} - \underline{\pi}]}{(R^N(1-\zeta) + \zeta \overline{R})^2} - (w^N - w^S) \tag{22}$$

Setting (22) less than zero:

$$\begin{aligned}
\frac{\partial \pi}{\partial R^N} &< 0 \\
\frac{\zeta \overline{R}[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} &< (R^N(1-\zeta) + \zeta \overline{R})^2 \\
\left(\frac{\zeta \overline{R}[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} \right)^{\frac{1}{2}} &< R^N(1-\zeta) + \zeta \overline{R} \\
\frac{1}{1-\zeta} \left(\frac{\zeta \overline{R}[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} \right)^{\frac{1}{2}} - \frac{\zeta}{1-\zeta} \overline{R} &< R^N \\
R^{N*} &< R^N
\end{aligned}$$

R^{N*} represents the quantity of northern researchers found from setting equation (22) equal to zero. Again, $R^N \in \{0, \overline{R}\}$. If the R^N value that sets equation (8) equal to zero is itself less than zero, then the slope of the profit function over the interval of interest will be strictly negative. If this is the case, then

$$\begin{aligned}
\frac{1}{1-\zeta} \left(\frac{\zeta \overline{R}[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} \right)^{\frac{1}{2}} - \frac{\zeta}{1-\zeta} \overline{R} &< 0 \\
\left(\frac{\zeta \overline{R}[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} \right)^{\frac{1}{2}} &< \zeta \overline{R} \\
\left(\frac{[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} \right)^{\frac{1}{2}} &< (\zeta \overline{R})^{\frac{1}{2}} \\
\frac{[\overline{\pi} - \underline{\pi}]}{\zeta (w^N - w^S)} &< \overline{R}
\end{aligned}$$

Therefore, when total research is greater than $\frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N-w^S)}$, the firm will find the highest profit by employing zero northern researchers and locating the research tasks entirely in the South. Likewise, if $R^N > \overline{R}$, then the profit function will be strictly increasing in the interval of interest. In this case, the firm will locate entirely in the north and set $R^N = \overline{R}$:

$$\begin{aligned}
\frac{1}{1-\zeta}\left(\frac{\zeta\overline{R}[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)}\right)^{\frac{1}{2}} - \frac{\zeta}{1-\zeta}\overline{R} &> \overline{R} \\
\left(\frac{\zeta\overline{R}[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)}\right)^{\frac{1}{2}} &> \overline{R} \\
\left(\frac{\zeta[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)}\right)^{\frac{1}{2}} &> \overline{R}^{\frac{1}{2}} \\
\frac{\zeta[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)} &> \overline{R}
\end{aligned}$$

So, for firms with small research needs, offshoring to the South will not be necessary. Therefore, the condition needed for an interior solution is:

$$\frac{\zeta[\overline{\pi}-\underline{\pi}]}{(w^N-w^S)} < \overline{R} < \frac{[\overline{\pi}-\underline{\pi}]}{\zeta(w^N-w^S)} \tag{23}$$

D Proof Of Result 2

Again, the northern firm in Case 2 is the only type of firm to be affected by IPR changes. So, the derivative of R^N wrt ζ in Case 2 is:

$$\frac{\partial R^N}{\partial \zeta} = \left(\frac{[\overline{\pi}-\underline{\pi}]}{\overline{R}(w^N-w^S)}\right)^{\frac{1}{2}}\left(\frac{1}{1-\zeta}\right)\left(\frac{\zeta^{\frac{1}{2}}}{1-\zeta}+\frac{1}{2\zeta^{\frac{1}{2}}}\right) - \left(\frac{1}{1-\zeta}\right)\left(1+\frac{\zeta}{1-\zeta}\right)$$

$$\frac{\partial R^N}{\partial \zeta} = \left(\frac{[\overline{\pi} - \underline{\pi}]}{\overline{R}(w^N - w^S)}\right)^{\frac{1}{2}} \left(\frac{1+\zeta}{(1-\zeta)2\zeta^{\frac{1}{2}}}\right) - \left(\frac{1}{1-\zeta}\right) \tag{24}$$

For the northern firm to increase northern research in the face of weaker IPR-protection, or $\frac{\partial R^N}{\partial \zeta} > 0$, the following must be true:

$$\begin{gathered}
\frac{\partial R^N}{\partial \zeta} > 0 \\
\left(\frac{[\overline{\pi} - \underline{\pi}]}{\overline{R}(w^N - w^S)}\right)^{\frac{1}{2}} \left(\frac{1+\zeta}{(1-\zeta)2\zeta^{\frac{1}{2}}}\right) > \left(\frac{1}{1-\zeta}\right) \\
\left(\frac{[\overline{\pi} - \underline{\pi}]}{\overline{R}(w^N - w^S)}\right)^{\frac{1}{2}} > \frac{2}{1+\zeta} \\
\left(\frac{[\overline{\pi} - \underline{\pi}]}{\zeta(w^N - w^S)}\right) \left(\frac{1+\zeta}{2}\right)^2 > \overline{R}
\end{gathered}$$

So, for a firm with a value of total research that is smaller than $\frac{[\overline{\pi} - \underline{\pi}]}{\zeta(w^N - w^S)} \left(\frac{1+\zeta}{2}\right)^2$, weakening of IPR-protection results in more northern research. Since ζ is less than one, it is not difficult to see that:

$$\frac{\zeta[\overline{\pi} - \underline{\pi}]}{(w^N - w^S)} < \frac{[\overline{\pi} - \underline{\pi}]}{\zeta(w^N - w^S)} \left(\frac{1+\zeta}{2}\right)^2 < \frac{[\overline{\pi} - \underline{\pi}]}{\zeta(w^N - w^S)}$$

Therefore, when the northern firm locates in both countries, its reaction to IPR reform will be ambiguous. Smaller firms in Case 2 will increase the amount of northern research when IPR-protection weakens, while the larger firms will react by lowering the amount of northern researchers.

References

[1] Alacer, Juan, and Minyuan Zhao. "Local R&D Strategies and Multilocation Firms: The role of Internal Linkages." *Management Science* 58.4 (2012).

[2] Alexeev, Michael, and Jim Leitzel. "Rent Shrinking." *Southern Economic Journal* 62.3 (1996): 620-626.

[3] Antras, Pol, and Elhanan Helpman. "Global Sourcing." *Journal of Political Economy* 112.3 (2004): 552-580.

[4] Baik, Kyung Hwan. "Effort Levels in Contests with Two Asymmetric Players." *Southern Economic Journal* 61.2 (1994): 367-378.

[5] Barefoot, Kevin. "U.S. Multinational Companies: Operations of U.S. Parents and Their Foreign Affiliates in 2010." Bureau of Economic Analysis. *Survey of Current Business* (2012): 51-74.

[6] Baye, Micahel R. and Heidrun C. Hoppe. "The Strategic Equivalence of Rent-Seeking, Innovation, and Patent-Race Games." *Games and Economic Behaviour* 44 (2003): 217-226.

[7] Branstetter, Lee, et al. "Intellectual Property Rights, Imitation, and Foreign Investment: Theory and Evidence." *National Bureau of Economic Research* (2007).

[8] Canals, Claudia, and Fuat ener. "Offshoring and Intellectual Property Rights Reform." *Journal of Development Economics* 108 (2014): 17-31.

[9] Carnahan, Seth, Rajshree Agarwal, and Benjamin A. Campbell. "Heterogeneity in Turnover: The Effect of Relative Compensation Dispersion of Firms on the Mobility and Entrepreneurship of Extreme Performers." *Strategic Management Journal* 33 (2012): 1411-1430.

[10] Chowdhury, Subhasish M. and Roman M. Sheremeta. "A Generalized Tullock Contest." *Public Choice* 147.3 (2011): 413-420.

[11] d'Aspremont, Claude, and Alex Jacquemin. "Cooperative and Noncooperative R&D in Duopoly with Spillovers." *The American Economic Review* 78.5 (1988): 1133-1137.

[12] Demirbag, Mehmet, and Keith W. Glaister. ”Factors Determining Offshore Location Choice for R&D Projects: A Comparative Study of Developed and Emerging Regions.” *Journal of Management Studies* 47.8 (2010).

[13] Dietl, Helmut, Egon Franck, Martin Grossmann, and Markus Lang. ”Contest Theory and its Applications in Sports.” *Working Paper* (2011).

[14] Dinopoulos, Elias, and Paul Segerstrom. ”North-South Trade and Economic Growth.” *Stockholm School of Economics* (2007).

[15] Dinopoulos, Elias, and Paul Segerstrom. ”Intellectual Property Rights, Multinational Firms, and Economic Growth.” *Journal of Development Economics* 92 (2010): 13-27.

[16] Dinopoulos, Elias, and Constantinos Syropoulos. ”International Diffusion and Appropriability of Technological Expertise.” *Advances in Applied Microeconomics* 7 (1998).

[17] Ekholm, Karolina, and Katariina Hakkala. ”Location of R&D and High-Tech Production by Vertically Integrated Multinationals.” *The Economic Journal* 117 (2007): 512-543.

[18] Ewerhart, Christian. ”Mixed Equilibria in Tullock Contests.” *Working Paper* 117 (2014).

[19] Fonseca, Miguel A. ”An Experimental Investigation of Asymmetric Contests.” *International Journal of Industrial Organization* 27 (2009): 582-591.

[20] Gambardella, Alfonso, Martin Ganco, and Florence Honore. ”Using What You Know: Patented Knowledge in Incumbent Firms and Employee Entrepreneurship.” *Organization Science*, forthcoming.

[21] Ganco, Martin. ”Cutting the Gordian Knot: The Effect of Knowledge Complexity on Employee Mobility and Entrepreneurship.” *Strategic Management Journal* 334(2013): 666-686.

[22] Glass, A. J., and Xiaodong Wu. ”Intellectual Property Rights and Quality Improvement.” *Journal of Development Economics* 82 (2007): 393-415.

[23] *Global Competitiveness Report 2009-2010. World Economic Forum* (2009).

[24] Grossman, Gene M., and Elhanan Helpman. "Integration vs Outsourcing in Industry Equilibrium." *The Quarterly Journal of Economics* 117.1 (2002): 85-120.

[25] Gustafsson, Peter, and Paul S. Segerstrom. "North-South Trade with Multinational Firms and Increasing Product Variety." *International Economic Review* 52.4 (2011): 11231155.

[26] Helpman, Elhanan. "Innovation, Imitation, and Intellectual Property Rights." *Econometrica* 61.6 (1993): 1247-1280.

[27] Hedge, Deepak, and Diana Hicks. "The Maturation of Global Corporate R&D: Evidence from the Activity of US Foreign Subsidiaries." *Research Policy* 37 (2008): 390-406.

[28] Henderson, Rebecca, and Iain Cockburn. "Scale, Scope, and Spillovers: The Determinants of Research Productivity in Drug Discovery." *The RAND Journal of Economics* 27 (1996): 32-59.

[29] Ito, Banri, and Ryuhei Wakasugi. "What Factors Determine the Mode of Overseas R&D by Multinationals? Empirical Evidence." *Research Policy* 36 (2007): 127512-87.

[30] Kamien, Morton I., Eitan Muller, and Israel Zang. "Research Joint Ventures and R&D Cartels." *The American Economic Review* 82.5 (1992): 1293-1306.

[31] Lai, Edwin L.-C., Raymond Riezman, and Ping Wang. "Outsourcing of Innovation." *Economic Theory* 38.3 (2009): 485-515.

[32] Leininger, Wolfgang. "More Efficient Rent-Seeking: A Munchhausen Solution." *Public Choice* 75.1 (1993): 43-62.

[33] Lewin, Arie Y., Silvia Massini, and Carine Peeters. "Why are Companies Offshoring Innovation? The Emerging Global Race for Talent." *Journal of International Business Studies* 40.6 (2009): 901-925.

[34] Melitz, Marc J. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica* 71.6 (2003): 1695-1725.

[35] Moncada-Paterno-Castello, Pietro, Marco Vivarelli, and Peter Voigt. "Drivers and Impacts in the Globalization of Corporate R&D: An Introduction Based on the European Experience." *Industrial and Corporate Change* 20.2 (2011): 583-603.

[36] Nitzan, Shmuel. "Modelling Rent-Seeking Contests." *European Journal of Political Economy* 10 (1994): 41-60.

[37] Skaperdas, Stergios. "Contest Success Functions." *Economic Theory* 7.2 (1996): 283-290.

[38] Snyder, James M. "Election Goals and the Allocation of Campaign Resources." *Econometrica* 57.3 (1989).

[39] *Unesco Science Report 2010* Unesco (2011).

[40] Zhao, Minyuan. "Conducting R&D in Countries with Weak Intellectual Property Rights Protection." *Management Science* 52.8 (2006): 1185-1199.

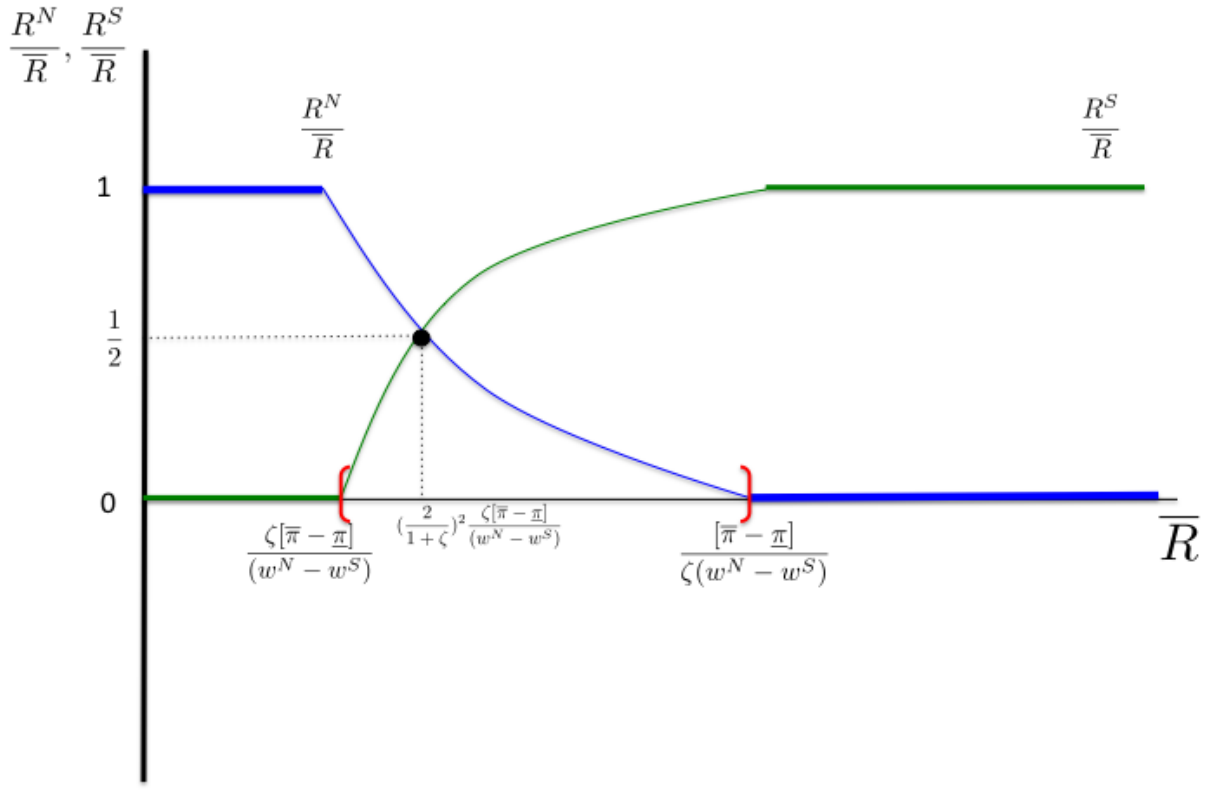

Figure 1: Optimal Research Ratios

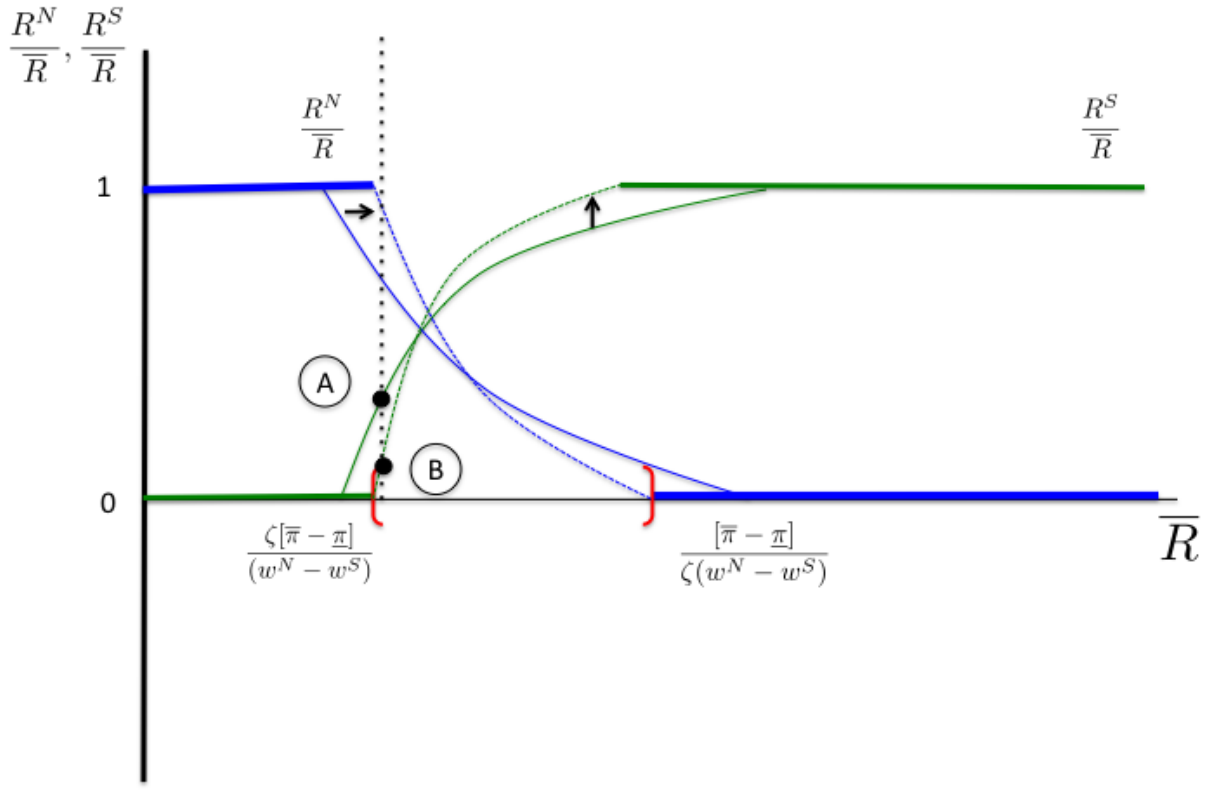

Figure 2: Weakening of IPR-protection yielding a decrease in R^S

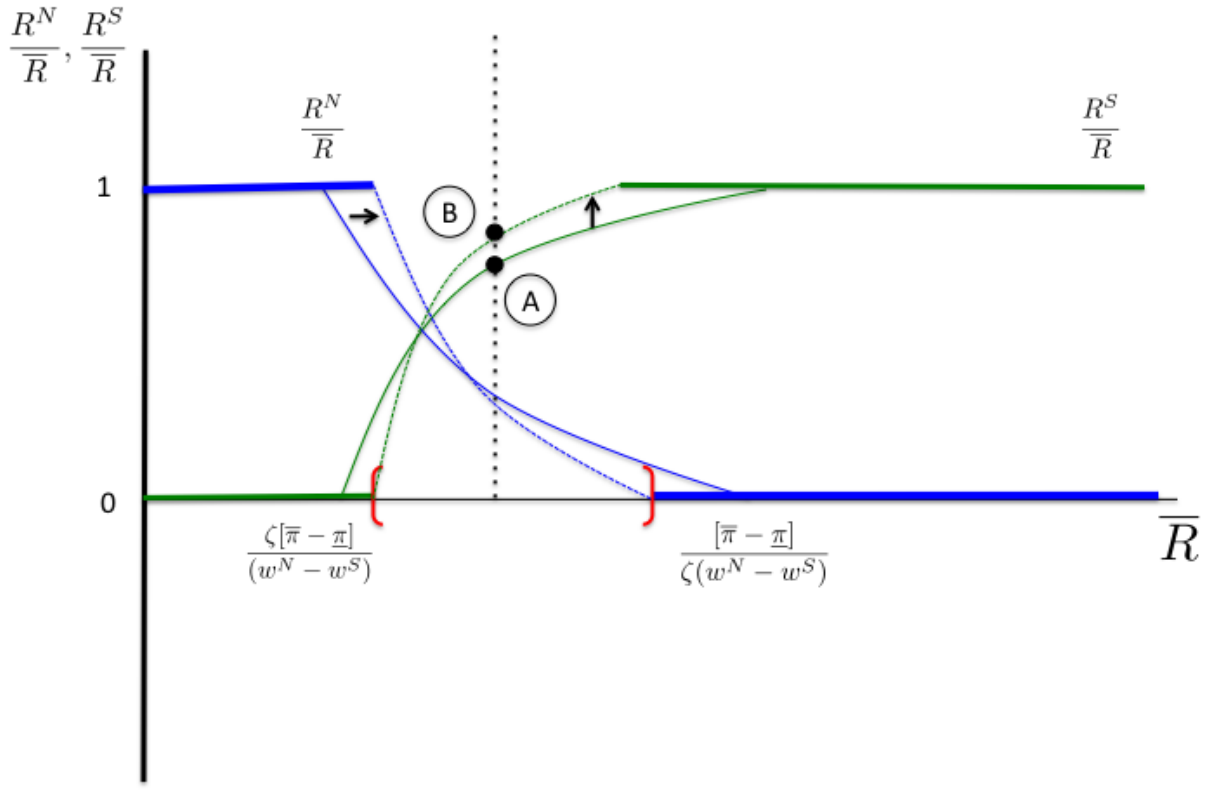

Figure 3: Weakening of IPR-protection yielding an increase in R^S

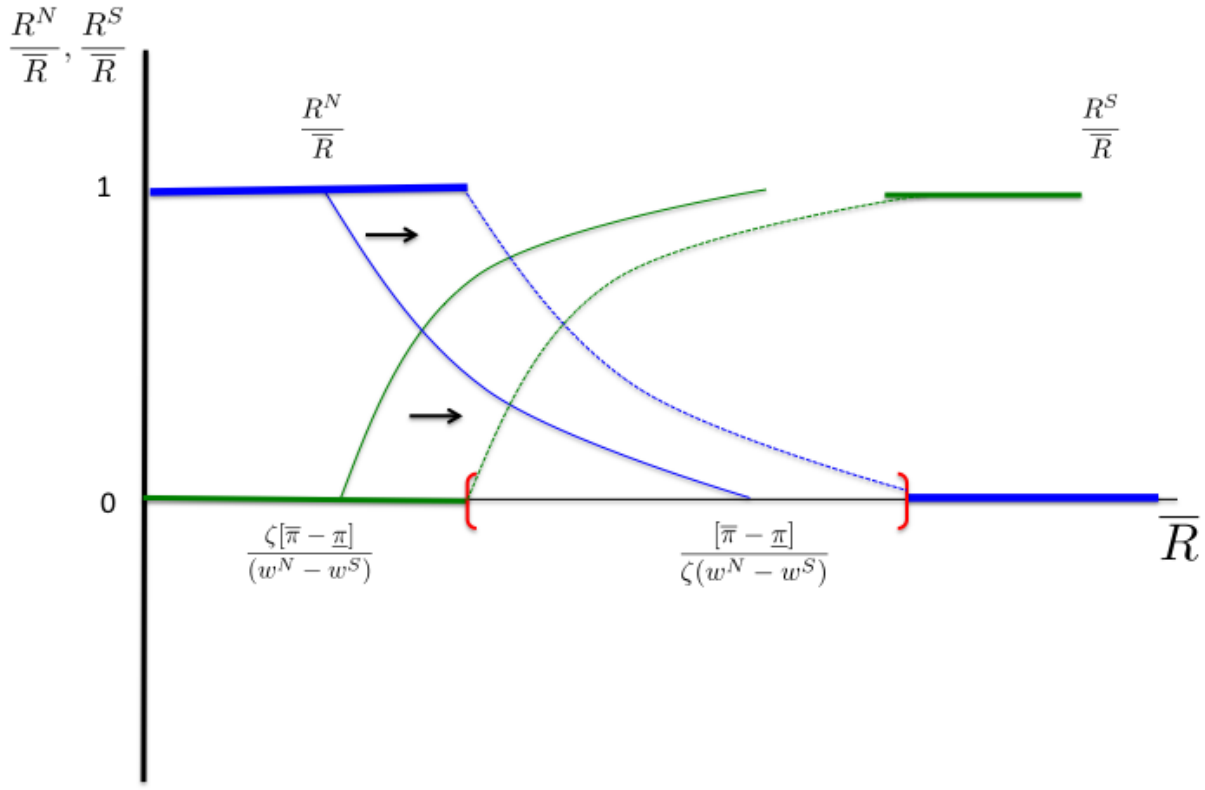

Figure 4: An increase in the penalty of imitation