Tax-Planning vs. Coordination: The Dual-Role of Internal Capital Allocation

Bin (Betty) Xing

School of Accounting and Finance,
University of Waterloo
bxing@uwaterloo.ca

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Abstract

How do firms' tax-planning strategies interrelate with other managerial objectives? I model a tradeoff between international tax-planning and the coordination of subsidiary-specific expertise in an MNC's capital allocation decision. The model shows that (1) when the internal struggle among subsidiaries is high, the MNC's responsiveness to tax incentives is low, and (2) tax incentives constrain the set of allocations that promote internal collaboration. I then model the implication of this tradeoff on how the MNC alters its capital allocation in response to a tax cut. The model predicts that a tax cut from a high-tax country alleviates subsidiaries' struggle against internal collaboration, but contrary to conventional wisdom, an MNC may reduce its capital allocation to that country. To empirically test these predictions, I use an exogenous event, the implementation of the "patent-box" regime, as the tax cut, and find evidence supporting the theory. Taken together, my study illustrates the interdependence of a firm's tax strategy and its managerial goals and the implications of this interdependence for the effects of a tax policy.

Keywords: capital allocation, resource management, international tax-planning, collaboration.

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I. Introduction

As the economy moves from being manufacturing driven to being innovation driven, the relationship among the international subsidiaires of many multinational corporations (MNCs) has also evolved. In the traditional manufacturing setting, subsidiaries often engage in a vertical relationship where a downstream subsidiary supplies a well-specified product to an upstream party. As international businesses strive in the innovation process, this vertical relationship no longer characterizes international subsidiaries. Instead, subsidiaries engage in a horizonal relationship where they work on an innovative project together, and each contributes its own expertise (Ghoshal and Bartlett 1990, Peng 2001, Sirmon et al. 2011, Birkinshaw, Hood, and Jonsson 1998, Gnyawalị, Singal, and Mu 2009). As subsidiaries take on new roles within the organization, the managerial challenges and the tax planning opportunities have also evolved.

Studies have examined the interaction between tax planning and the managerial objective within the traditional manufacturing setting. In a decentralized organization, the headquarters face information asymmetry regarding the local market condition and so cannot dictate an optimal quantity to be supplied from a downstream subsidiary. In the traditional manufacturing setting, the transfer price set on the products being supplied form the downstream to the upstream party serves to incentivize appropriate subsidiary action in the form of production quantity (Baldenius and Reichelstein 2006, Hirshleifer 1956, Smith 2002a). An issue specific to multinational corporation is the tax implications of an international transfer price between subsidiaires in different jurisdictions. Extant literature has documented that an MNC's transfer pricing decision faces a tradeoff between the tax and the managerial objective and shown that the transfer price that minimizes tax payments does not incentivize the optimal level of production (Baldenius, Melumad, and Reichelstein 2004, Hiemann and Reichelstein 2012, Smith 2002b, Choe and Hyde 2008, Hyde and Choe 2005).

In the innovation process, the intellectual input from each subsidiary toward an innovative project is difficult to specify and cannot be transferred or priced. As a result, the managerial concern is no longer on the transfer price but the ability to coordinate subsidiary collaboration. The literature has not examined the tradeoff between the tax objective and the managerial objective of coordination when subsidiaires share a horizontal collaborator relationship. In this paper, I study how an MNC trades off the tax objective of minimizing global tax payments against the managerial objective of coordinating subsidiary-specific resources (in the form of knowledge and expertise) in allocating capital among its international subsidiaires.

I study the capital allocation decision because resources exist in many forms, and a firm's ability to manage its various types of resources forms its core competency (Sirmon et al. 2011, Amit and Schoemaker 1993). An MNC's ability to respond quickly to changes in local conditions is a key success factor in capturing market share in local markets. As a result, in the process of growing internationally, subsidiaries often gain autonomy in decision-making and develop unique expertise shaped by their own local conditions (Birkinshaw 1996, Birkinshaw, Hood, and Jonsson 1998). This growth strategy promotes international subsidiaries to accumulate subsidiary-specific resources in the form of knowledge, processes, and expertise. Although the MNC has accumulated a wide web of knowledge, for many, the ability to coordinate knowledge-sharing among subsidiaries is critical to effectively using their subsidiary-specific resources, especially in the process of innovation (Gupta and Govindarajan 2000, Paterson and Brock 2002, Ram and Pietro 2004, Dellestrand and Kappen 2012, Castellani, Castellani, and Zanfei 2006). I examine the effect of the central allocation of one type of resource (capital) on the coordination of another type of resource (subsidiary-specific knowledge) and how it interrelates with international tax-planning incentives.

Understanding this interaction between tax planning and the MNC's internal management in the capital allocation decision also has tax policy implications. Countries often justify their corporate tax reduction with the goal to attract capital investment from businesses, as evidenced in the tax competition among countries and in the most recent U.S corporate tax cut (Clausing 2007, Nigel Chalk 2018). In addition to the general corporate tax reduction, countries have also considered or adopted regimes that offer significant tax cut specific to innovation related activities, such as the "patent-box" regime (Alstadsæter et al. 2015, Bradley, Dauchy, and Robinson 2015, Griffith, Miller, and O'Connell 2010, Chen et al. 2018). One of the major objectives stated by countries that have adopted this regime is to attract capital and other innovative resources. This objective is also shared among countries that are in the process of lobbying for such a regime (Joint Economic Committee 2016, Canadian Chamber of Commerce 2018). In this study, I model and test how capital allocation changes in response to a tax cut. I find that whether an MNC positively responds to such a tax policy depends on how the policy changes the tradeoff that the MNC faces. The model predicts that the MNC could reduce capital allocation in response to the tax cut when the benefit to internal coordination is high. Using the patent-box regime as my empirical setting, I find empirical evidence consistent with this prediction. This counterintuitive result stresses the importance of considering the internal management of an MNC in assessing the impact of a tax policy.

I model the tradeoff in a coordination game where the headquarters allocates a certain amount of capital between two international subsidiaries. I capture each subsidiary's choice to share its expertise by its choice between two projects. One project can be completed alone and yields a lower return. The other project is innovative and yields a higher return, but the benefits can be realized only if both subsidiaries choose to work on it. Once a subsidiary chooses its project, both the capital allocated from the headquarters and its subsidiary-specific resources that are relevant to the project are dedicated to the project of choice. Knowledge-sharing occurs when both subsidiaries choose the higher-return project. Because their choice of project depends on the headquarters' capital allocation, the central allocation of capital plays a coordination role in facilitating knowledge-sharing among subsidiaries. The knowledge-sharing scenario involves two subsidiaries working on a common project, so I refer to this outcome as "collaboration" and use the two terms interchangeably.

This setup studied in this model distinguishes from prior literature in several ways. First, unlike in the transfer pricing literature, the intellectual contribution from each subsidiary takes the form of knowledge and expertise and cannot be specified or transferred (Gnyawalị, Singal, and Mu 2009, Leiponen and Helfat 2010). This is true especially during the prototype stage of the innovation development (Regnell et al. 2009). As a result, it is impossible to contract on the exact intellectual input from each party. This aspect of the lack of contractibility is consistent with the characteristics of the R&D project as assumed in Johnson (2006). Second, in the horizonal collaborator relationship, subsidiaries simultaneously decide on whether to share expertise and participate in an innovative project instead of one subsidiary making a relationship-specific investment first that is then followed by further development by a second subsidiary as in Johnson (2006) and De Simone and Sansing (2019). Finally, unlike the setup of the relationship-specific investment studies where the first subsidiary could independently realize the value of its input by selling the first-stage development externally, in the collaborator relationship, the realization of each subsidiary's expertise depends on having the expertise from the other subsidiary. In other words, if a subsidiary chooses not to engage in the innovation process, its expertise remains in the knowledge state and cannot be sold externally at a high price.

The tax consequence of the capital allocation arises from the different tax rates faced by the two subsidiaries. For tax reasons, the headquarters prefers allocating capital to the low-tax subsidiary.[1] However, if the headquarters minimizes taxes and allocates all the capital to the low-tax subsidiary, the low-tax subsidiary may no longer prefers collaboration. This is because although collaborating on the innovation project yields a higher return, the payoff after sharing with the other subsidiary can be lower. With a large amount of capital, it could earn a high payoff by working alone on the traditional project even though it earns a lower return.[2]

The model offers three key insights. First, tax-planning dominates the allocation decision when there is no internal struggle against collaboration and both subsidiaries choose the higher-return project regardless of how the headquarters allocates capital. Second, when there is a struggle, the tax rate difference creates a tax cost associated with inducing collaboration. Therefore, for some projects, the benefit of inducing collaboration is below the tax cost associated with it. The MNC forgoes inducing collaboration, and tax-planning again dominates the allocation decision. Third, for other projects, the benefit of inducing collaboration exceeds the tax cost, and the MNC will induce collaboration with the lowest tax cost possible. Note that because the absolute tax-minimizing allocation hinders collaboration, the optimal allocation minimizes tax only within the set of allocations that can induce collaboration.

After establishing this baseline relationship, I study the tax policy implication of this tradeoff by considering how the MNC alters its capital allocation in response to a tax cut from a high-tax jurisdiction. I first model a general tax cut that applies to both types of projects. I then

[1] This model resembles a real income shifting strategy instead of a "paper shifting" strategy. In this model, the profit earned from the capital investment from each subsidiary is then taxed in the respective jurisdiction. The sharing of the benefit from the collaborative effort occurs after all the taxes are paid, so the sharing rule governs how the two parties will be rewarded rather than deciding how the profit will be taxed.

[2] In this model, the sharing of the total after-tax profit is not tied with the capital allocation. How the two subsidiaries share the reward from the innovative effort is a constant determined prior to the allocation. One motivation for this choice is that a party negotiates for its share of the total reward based on its intellectual contribution that is independent from the capital allocation.

use the patent-box setting to formulate a testable hypothesis. A patent-box regime taxes income from innovation-related activities at a rate much lower than the regular corporate tax rate applicable to other types of income. I model the patent-box regime by considering a tax cut that applies only to the innovative project that requires the expertise from both subsidiaires.

I find that whether the MNC increases, decreases, or maintains its capital allocated to the high-tax subsidiary depends on how valuable internal collaboration is. Two aspects of the tax cut create four cases on the capital allocation changes. The first aspect reduces the tax cost associated with inducing collaboration. As a result, among projects that do not yield high enough returns to overcome the tax costs before the tax cut, there are two possible outcomes after the tax cut. First, some projects can now overcome the reduced tax cost and become worth inducing only after the tax cut, so that headquarters starts allocating capital to the high-tax subsidiary after the tax cut. This is the case where capital allocation increases for the high-tax subsidiary. However, there are projects with returns that are still not high enough to overcome even the reduced tax cost after the tax cut. Tax-planning still dominates after the tax cut and there is no change to capital allocation in this case.

The second aspect of the tax cut alleviates subsidiaries' struggle against internal collaboration. The tax cut increases the payoff that the high-tax subsidiary can share with the low-tax subsidiary, and thus makes collaboration more attractive to the low-tax subsidiary. As a result, the MNC can allocate more capital to the low-tax subsidiary without jeopardizing collaboration. The insight that the MNC may optimally allocate less capital to the country offering a tax cut is a unique contribution of the model, beyond conventional wisdom. Finally, if there is no struggle against internal collaboration even before the tax cut, then the MNC does not alter capital allocation after the tax cut because it can minimize tax and induce collaboration both before and after the tax cut. In summary, the theory predicts that when a high-tax county implements a patent-box regime, an MNC reduces capital allocated to subsidiaries in the high-tax country if the value of internal collaboration is high, and vice versa.

I test the theory's prediction using the patent-box regime as my empirical setting. This setting offers several advantages. First, both the timing and the implementation of the regime is exogenous to the firm, so this setting offers a clear identification strategy. Second, compared to a gradual corporate tax reduction, the patent-box regime offers a drastic reduction. By administering a stronger treatment, this setting provides empirical tests a better chance at detecting the treatment effect. Third, an important aspect of the model is that the tax cut must apply to a project with a higher return that is realizable only if the subsidiaires collaborate on the project. The patent-box setting closely resembles this element of the model by applying a low tax rate on innovative activities that are most likely to require collaboration among subsidiaires (Castellani, Castellani, and Zanfei 2006, Singh and Fleming 2010, Zhang and Tang 2017). Finally, operationalizing the theoretical construct of collaboration requires the observation of collaborative efforts. In the management literature, both Toh and Polidoro (2013), Fleming, Mingo, and Chen (2007), and Singh and Fleming (2010) suggest that the co-inventor information filed with patent applications accurately reflects the collaboration efforts undertaken. Therefore, by focusing the empirical test in the patent development setting, I could use the inventor information from patent applications to proxy for collaboration.

I use two data sources to construct resource proxies at the country-industry level. I use the Business Enterprise Research and Development (BERD) database from the Organization for Economic Cooperation and Development (OECD) to construct measures that proxy for R&D input. I use the patent applications to construct measures that proxy for R&D output. Although the country-industry observation aggregates decisions from firms of the same industry within a country, testing the hypothesis at the country-industry level has several limitations. First, the aggregate measure averages out the variation at the individual firm level, making it more difficult to detect the relationship using the aggregate measure. Second, although the direction of the prediction is the same between firm-level and country-industry-level analysis, it is difficult to extrapolate firm-level interpretations of the coefficients from the country-industry-level findings. Finally, whether a subsidiary is high- or low-tax largely depends on the corporate structure. With country-industry observations, whether a country is high- or low-tax becomes difficult to determine. To alleviate this concern, I restrict my sample to countries with the highest tax rates.

This study makes several contributions to the literature that examines the interaction between tax planning and managerial decision making. First, it incorporates a horizontal and collaborative relationship among subsidiaries that is more common in innovation processes. Second, whereas most prior studies address the managerial challenge faced in a production setting, this study addresses the challenge to coordinate subsidiary-specific expertise in an innovation setting. Finally, this study considers the interplay between the tax and the managerial objective in the capital allocation decision, an overlooked decision in the literature.

This study also contributes to the discussion of the patent-box regime by explaining the how MNCs may respond differently to the regime depending on the value of internal collaboration, a factor that the theory uniquely identifies. This study uses an empirical proxy on collaboration from the management literature to examine a new dimension of the tax-planning decision. The findings of this study complement prior literature that studies the effect of the patent-box regime on innovation activities (Alstadsæter et al. 2015, Böhm et al. 2015, Karkinsky and Riedel 2012, Bornemann, Laplante, and Osswald 2019, Schwab and Todtenhaupt 2019). .

II. Model Setup

A multinational corporation (MNC) has a headquarters office and two wholly owned international subsidiaries, H and L. Subsidiary H is located in a high-tax jurisdiction with a corporate tax rate $\tau + h$ where $h > 0$, while subsidiary L is located in a low-tax jurisdiction with a corporate tax rate τ. In the base case, the tax differential between the two subsidiaries is h. To study the effect of an exogenous tax event, in the next section, the model considers the introduction of a tax cut from the high-tax country that reduces the tax differential from h to p.

The model has three players, the headquarters and the two subsidiaries, that are involved in a sequential game. The headquarters (HQ) moves first and allocates a certain amount of capital (λ) between the two subsidiaries with the objective to maximize total payoff. Subsidiaries H and L receive the amount of capital of λ^H and λ^L, respectively, from the allocation. The two subsidiaries compete in the sense of Stein (1997) to access the same pool of capital.

After the headquarters' move, the two subsidiaries move simultaneously by choosing one of two projects to undertake, with each subsidiary maximizing its own payoff with its choice. One project is innovative and has a higher pre-tax return, but this return is only realized if both subsidiaries select the project. This is because each subsidiary is endowed with subsidiary-level expertise (knowledge, processes, or advanced technology), and the success of the innovation requires both sets of expertise. The other project can be completed alone but has a lower pre-tax return (the defensive project). Once a subsidiary chooses a project, both the capital allocated to the subsidiary and any subsidiary-level resources that are relevant to the project are devoted to the project of choice. When both subsidiaries choose the efficient project, they bring their respective subsidiary expertise and work together on a common project. Knowledge-sharing occurs through collaboration, and the headquarters achieves the coordination of subsidiary-specific resources.

Once the returns of the projects are realized, each subsidiary receives its payoff. The payoff is a function of the pre-tax return, the tax rates faced by the two subsidiaries, and how the two subsidiaries share the after-tax profits if they work together on the efficient project. I adapt the model setup from Rajan, Servaes, and Zingales (2000). Let the first entry of the strategy profile be subsidiary H's strategy and the second entry be subsidiary L's and let (π_H, π_L) denote the payoff pairs. Figure 1 depicts the timeline of events and the following payoff matrix summarizes the payoff to each player corresponding to each strategy profile.

(π_H, π_L)		H	
		Efficient	Defensive
L	Efficient	$(\pi_H^{E,E}, \pi_L^{E,E})$	$(\pi_H^{D,E}, \pi_L^{D,E})$
	Defensive	$(\pi_H^{E,D}, \pi_L^{E,D})$	$(\pi_H^{D,D}, \pi_L^{D,D})$

The payoff to each player depends on the return of the project and the player's tax rate. The defensive project has a pre-tax return of β and the efficient project has a higher pre-tax return of $\beta + \gamma$ $(\gamma > 0)$. The parameter γ captures the incremental benefit to the MNC of having the two subsidiaries working together on the efficient project. Subsidiary H has an after-tax return of $(1 - \tau - h)(\beta + \gamma)$ on the efficient project and an after-tax return of $(1 - \tau - h)\beta$ on the defensive project. Subsidiary L has an after-tax return of $(1 - \tau)(\beta + \gamma)$ on the efficient project and an after-tax return of $(1 - \tau)\beta$ on the defensive project. Note that across the two subsidiaries, the pre-tax return is the same for each project, so tax is the only factor that contributes to the difference in the after-tax returns between the two subsidiaries.

Payoff Associated with Strategy Profile (E,E):

$$\pi_H^{E,E} = (1-\omega)\big((1-\tau-h)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L\big)$$

$$\pi_L^{E,E} = \omega\big((1-\tau-h)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L\big)$$

Under strategy profile (E,E), both subsidiaries choose the efficient project. They share their respective expertise through working together on the efficient project. The payoff associated with this outcome has three features that reflect the nature of an internal collaboration as discussed in Katz and Martin (1997). First, the two subsidiaries share the rewards from the common project. Let $\omega \in (0,1)$ be the percentage of the total rewards from the joint project that subsidiary H receives. It follows that the percentage that subsidiary L receives is $1-\omega$. Furthermore, the sharing rule is predetermined by the headquarters, so both subsidiaries know their share of the rewards before choosing the project.

Second, the sharing rule, ω, is a predetermined constant and is known to the subsidiaries before they choose their actions, but it is not contractible on any performance measure. As discussed in Beaudry and Schiffauerova (2011), the contribution toward an innovation collaboration often takes the form of knowledge, expertise, or other intellectual capacities. The intellectual exchanges among collaborators are difficult to specify and contract upon (Hart and Moore 1999). Contracting on the output of an innovation collaboration is similarly difficult (Johnson 2006). If the collaborators successfully develop the technology and deliver the product to the market, then the innovation succeeds and earns a return that the market assigns. However, the firm may still achieve softer objectives such as knowledge-sharing even if no new product is delivered to the market (Leiponen and Helfat 2010). These objectives are valuable to future endeavors and team development, but the exact value is difficult to assess.

Payoff Associated with Strategy Profile (D,D):

$$\pi_H^{D,D} = (1 - \tau - h)\beta\lambda^H$$

$$\pi_L^{D,D} = (1 - \tau)\beta\lambda^L$$

The (D,D) outcome captures the scenario when neither subsidiary chooses the efficient project. They work on their respective projects independently and do not share the payoff. Each receives the payoff from the defensive project after paying their respective taxes.

Payoff Associated with Strategy Profile (D,E):

$$\pi_H^{D,E} = (1 - \tau - h)(\beta + \epsilon)\lambda^H$$

$$\pi_L^{D,E} = (1 - \tau)(\beta + \gamma - \theta)\lambda^L$$

Outcomes (D,E) and (E,D) are scenarios where one subsidiary chooses to work on the efficient project alone. If subsidiary H chooses D, subsidiary L must attempt the efficient project on its own without the expertise from subsidiary H. As a result, the return on the efficient project is much lower compared to when both subsidiaries work together on the project. Note that in the payoff that subsidiary L will receive, $\pi_L^{D,E}$, the return decreases from $\beta + \gamma$ to $\beta + \gamma - \theta$, where θ captures the cost of replacing the missing expertise from subsidiary H. Because the success of the efficient project depends critically on the contribution from both subsidiaries, the cost for attempting it alone (θ) is so large that $\theta > \gamma$. The difficulty for a subsidiary to innovate alone is often cited as the reason for firms' use of internal collaborations in advancing innovation (Howard et al. 2016, Zhang and Tang 2017, Singh and Fleming 2010).

To illustrate the advantage of internal collaboration in the process of innovation, I provide a stylized example below. Suppose the firm is in the healthcare industry and one of its hospital clients approaches the firm for a new patient-monitoring technology. If the firm can successfully deliver the technology, not only will it win the contract with the hospital, but also the pilot-testing at the hospital will significantly enhance the success of commercializing the product for senior homes in the future. Suppose that the Canadian subsidiary has data and knowledge on patient behavior, but the U.S. subsidiary has the machine-learning technique of picture processing. The new technology aims at accurately detecting motion and to alert at abnormal behaviors. The success therefore requires adapting picture processing technology onto patient behaviors, the expertise from both subsidiaries. If the U.S. subsidiary does not supply the technique, the Canadian subsidiary may acquire it from a third party but would incur a high cost.

The payoff to subsidiary H that chooses the defensive project does not differ much whether the other subsidiary also chooses the defensive project or works alone on the efficient one. The only difference is that although subsidiary H does not contribute to the efficient project, it is possible that the achievement by subsidiary L brings a small positive externality, such as an enhanced reputation to subsidiary H. Let $\epsilon > 0$ be this small positive externality. Because this small amount is assumed to be negligible, I set it as zero.[3]

Payoff Associated with Strategy Profile (E,D):

$$\pi_H^{E,D} = (1 - \tau - h)(\beta + \gamma - \theta)\lambda^H$$

$$\pi_L^{E,D} = (1 - \tau)(\beta + \epsilon)\lambda^L$$

By symmetry, when subsidiary H attempts the efficient project alone, it receives a pre-tax return of $\beta + \gamma - \theta$, where $\theta > \gamma$. When subsidiary L chooses the defensive project, it receives a pre-tax return of $\beta + \epsilon$, where ϵ is the small positive externality conferred by the other subsidiary.

[3] Taking a small but non-zero number yields qualitatively similar results but involves some technical complexity. I plan to report this analysis in future work.

III. Base Case Solution – Solving for Optimal Allocation

In this sequential game, the headquarters moves before the subsidiaries, so I apply backward induction and first solve the subsidiary-level game.

Subsidiary-Level Decision: Sub-game Perfect Equilibria

In the sub-game, the two subsidiaries take the headquarters allocation decision λ^H, λ^L as given and move simultaneously in a strategic game, so I solve for the sub-game perfect equilibria of their strategic game. Proposition 1 presents the solution and characterizes the subsidiaries' choices between the two projects. For the purpose of tractability and brevity, I present my main analysis using $\omega = \frac{1}{2}$. The analysis using a general ω offers the same insights but is lengthy in presentation, so I document those results in Appendix I. The proofs to all the propositions can be found in Appendix II.

Proposition 1.

1. (D,D) is a sub-game perfect equilibrium for any λ^H, λ^L.
2. (a) If $\gamma > \beta$, (E,E) is a sub-game perfect equilibrium for any λ^H, λ^L.

   (b) If $\gamma \leq \beta$, (E,E) is a sub-game perfect equilibrium if and only if

$$\lambda^H \leq s_H \text{ and,}$$
$$\lambda^L \leq s_L$$

where,

$$s_H = \frac{(1-\tau)(\beta+\gamma)}{(2-2\tau-h)\beta+h\gamma}\lambda$$
$$s_L = \frac{(1-\tau-h)(\beta+\gamma)}{(2-2\tau-h)\beta-h\gamma}\lambda$$

That is, a subsidiary prefers not to collaborate when it is allocated too much capital.

I make a few observations from Proposition 1. First, because the cost of attempting innovation alone (θ) is so large that it exceeds the benefit of doing so (γ), it is not worthwhile for either subsidiary to complete the efficient project alone. Therefore, if one subsidiary chooses D, the other subsidiary will not choose E, so (D, D) is always an equilibrium.

Second, a subsidiary opposes working together on the efficient project when its share of the total payoff is too small compared to the payoff it could receive from working on the defensive project alone. This occurs when the subsidiary is allocated too much capital. Although the efficient project has a higher return, the payoff must be shared, whereas the subsidiary keeps all the payoff from the defensive project to itself. On the other hand, sharing payoff from the efficient project is very appealing to a subsidiary when the alternative of working on its own earns a lower payoff. This occurs if the subsidiary is not allocated too much capital.

As illustrated in Figure 2, at one extreme, when a subsidiary is allocated no capital, it clearly prefers working together on the efficient project over working alone on the defensive project. At the other extreme, when a subsidiary is allocated all the capital, it clearly prefers working along over sharing profit from the efficient project. At some point between the two extremes, the subsidiary's preference flips. In Figure 2, s_L is the point at which subsidiary L flips its preference. The change of preference associated with being allocated too much capital is the main internal struggle against collaboration on the efficient project.

Third, the tax rate differential between the two subsidiaries exacerbates the problem. At any fixed value of γ, s_L decreases in h. In other words, the low-tax subsidiary is more likely not to collaborate when the tax rate differential between the two subsidiaries is high. To see this result, suppose that capital is allocated equally between the two subsidiaries. Without a tax rate differential, sharing would be equally appealing to both subsidiaries. However, when the two subsidiaries are subject to different tax rates, sharing is no longer equally appealing to both subsidiaries. The low-tax subsidiary has more after-tax profits to offer and thus finds sharing (through collaboration) with the high-tax subsidiary less appealing. The higher the tax differential is, the less appealing collaboration becomes to the low-tax subsidiary. Therefore, from the subsidiaries' perspective, the tax rate difference is not neutral to their incentives toward working together on the efficient project.

Finally, this internal struggle does not always exist. If the efficient project yields a high enough return such that the profits are higher even after sharing with the other party, then even the subsidiary with all the capital will always prefer collaborating on the efficient project.

Optimal Allocation by Headquarters

After solving for the subsidiaries' action, I return to solving the optimal allocation strategy of the headquarters, anticipating the subsidiaries' behavior in the sub-game.

Proposition 2. The optimal allocation $(\lambda^{H*}, \lambda^{L*})$ is

1. $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma > \beta$
2. $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma < \frac{h}{2(1-\tau)-h}\beta$
3. $(\lambda^{H*}, \lambda^{L*}) = (\lambda - s_L, s_L)$ if $\frac{h}{2(1-\tau)-h}\beta < \gamma < \beta$

Proposition 2 offers three key insights into how a firm's tax-planning strategy interrelates with its other managerial objectives. First, the MNC takes full advantage of the tax-planning opportunity when tax-planning does not conflict with other managerial objectives. If tax-planning dominates the allocation decision, the MNC will allocate all the capital to the low-tax subsidiary. However, this only occurs under two scenarios. In the first scenario, the low-tax subsidiary prefers collaborating on the efficient project even when it has all the capital. The MNC achieves both tax minimization and the two subsidiaries working together on the efficient project. This is the first-best and there is no tradeoff.

When the first-best cannot be achieved, the presence of a tax-planning opportunity creates a tax cost to coordinate the two subsidiaries to collaborate on the efficient project. The headquarters must allocate some capital to the high-tax subsidiary to coordinate collaboration, but each dollar of capital allocated to the high-tax subsidiary attracts higher tax. Therefore, the headquarters faces a tradeoff between the benefits of having the two subsidiaries collaborating on the efficient project and the tax costs associated with this. If it is too costly to induce collaboration, the headquarters will optimally forgo collaboration and focus only on tax-planning.

Third, the objective to coordinate the two subsidiaries to collaborate on the efficient project sometimes interacts with the tax-planning opportunities to create an interior solution. In this case, among the allocations that support the collaboration outcome, the one that minimizes tax is the optimal allocation. Therefore, the headquarters allocates as much capital as the collaboration outcome permits to the low-tax subsidiary. The optimal allocation therefore is to allocate s_L to the low-tax subsidiary and the remaining amount to the high-tax subsidiary, where s_L is the point above which subsidiary L flips its preference.

Note that the tax rate differential between the two subsidiaires is not "tax-neutral" from the headquarters' perspective and reduces the set of optimal allocations that support internal collaboration. First, without the tax rate difference, the headquarters would always induce the two subsidiaries to work together on the efficient project. However, because of the tax cost associated with the tax rate differential, collaboration is not always worth inducing. Second, without the tax-planning opportunities, the MNC would be indifferent among all allocations that induce collaboration. However, the tax rate difference causes the headquarters to prefer allocating more to the low-tax subsidiary.

IV. Exogenous Tax Policy Change – A Tax Cut

It is evident that countries race to the bottom with their tax rates (Clausing 2009, 2016, 2007, Desai, Foley, and Hines 2003). Facing competition from low-tax jurisdictions, high-tax countries have reduced their corporate tax rates, hoping to attract more businesses and creating more jobs. Do these tax reductions always cause MNCs to allocate more capital toward these countries? I address this question by considering how the MNC changes its capital allocation to the high-tax subsidiary after a tax cut.

I first consider a general corporate tax reduction in the high-tax country and examine whether the high-tax subsidiary receives more capital after the tax cut. A general rate reduction reduces the corporate income tax rate on all types of taxable income earned in the corporation. As an example, Canada introduced the General Rate Reduction that has reduced the corporate tax rate by 13% since 2000. The most recent U.S. tax reform (*Tax Cuts and Jobs Act of 2017*) provides a flat corporate tax cut from 35% to 21%. In the context of the model, a general rate reduction reduces the tax rates on income earned from both projects.

Suppose that a high-tax country reduces its tax rate from $\tau + h$ to $\tau + p$, where $p < h$ and this reduction applies to both the efficient and defensive project. Applying the same technique that solves the base case, I solve for the MNC's capital allocation after the tax cut. Let the optimal allocation to subsidiary H and L be λ_p^{H*} and λ_p^{L*}, respectively where subscript p denotes the scenario where the tax difference between the two subsidiaries decreases from h to p. The following lemma summarizes this allocation and is a straight application of Proposition 2.

Lemma 1.

The optimal allocation $(\lambda_p^{H*}, \lambda_p^{L*})$ after the general tax reduction is characterized by:

1. $(\lambda_p^{H*}, \lambda_p^{L*}) = (0, \lambda)$ if $\gamma > \beta$
2. $(\lambda_p^{H*}, \lambda_p^{L*}) = (0, \lambda)$ if $\gamma < \frac{p}{2(1-\tau)-p}\beta$

3. $(\lambda_p^{H*}, \lambda_p^{L*}) = (\lambda - s_{L,p}, s_{L,p})$ if $\frac{p}{2(1-\tau)-p}\beta < \gamma < \beta$, where

$$s_{L,p} = \frac{(1-\tau-p)(\beta+\gamma)}{(2(1-\tau)-p)\beta - p\gamma} \cdot \lambda$$

The next proposition compares the allocation before and after the tax cut and characterizes how capital allocation to the high-tax subsidiary changes as a result of the tax cut. Contrary to conventional wisdom, the tax cut does not always result in an increase in capital allocated to the high-tax subsidiary.

Proposition 3.

1. When $\gamma > \beta$ or $\gamma < \frac{p}{2(1-\tau)-p}\beta$, $\lambda_p^{H*} = \lambda^{H*}$
2. When $\frac{p}{2(1-\tau)-p}\beta < \gamma < \frac{h}{2(1-\tau)-h}\beta$, $\lambda_p^{H*} > \lambda^{H*}$
3. When $\frac{h}{2(1-\tau)-h}\beta < \gamma < \beta$, $\lambda_p^{H*} < \lambda^{H*}$

Proposition 3 offers four insights. First, the MNC may optimally choose to not respond to the tax policy. The first case of this proposition describes two scenarios when this happens. In the first scenario, there is no internal struggle against collaboration, so the MNC achieves both tax minimization and collaboration, both before and after the tax cut. Here, even though the tax-minimizing strategy allocates all capital to the low-tax subsidiary, the return from the collaboration is high enough for the low-tax subsidiary to still prefer collaboration.

Second, the tax cut from the high-tax country reduces the tax cost associated with collaboration by reducing the tax rate difference between the two subsidiaries. However, the return on some projects is still too low to be worthwhile inducing, even at a reduced cost. At these low incremental returns, the MNC would not induce collaboration either before or after the tax cut, and its optimal strategy is to allocate all capital to the low-tax subsidiary, even after the tax cut. The second scenario in case 1 corresponds to this situation.

Third, because the tax cut reduces the cost of inducing collaboration, some projects only become worth inducing after the tax cut, and the MNC increases allocation to the high-tax subsidiary only in this situation. By allocating some capital to the high-tax subsidiary (instead of allocating all resources to the low-tax subsidiary), the MNC incurs a tax cost but the two subsidiaries collaborate on an efficient project that yields a return high enough to offset the tax cost. Case 2 of Proposition 3 describes this situation. The threshold that determines whether a project is worth inducing after the tax cut depends on how much the tax cut is. The higher the tax cut, the more it reduces the cost of inducing collaboration and the more likely collaboration is worthwhile. In algebraic terms, a smaller p corresponds to a lower threshold.

Finally, if the efficient project is worth inducing even without the tax cut, then it is surely worth inducing after the tax cut. However, the tax cut offered by the high-tax country alleviates the internal struggle against collaboration and allows the MNC to allocate even more to the low-tax subsidiary. The tax cut increases the after-tax profit the high-tax subsidiary can share with the low-tax subsidiary, thereby making collaboration more appealing to the low-tax subsidiary. As a result, the headquarters can allocate more capital to the low-tax subsidiary while preserving the low-tax subsidiary's preference for collaboration. In Figure 3, the tax cut creates an upward shift in the low-tax subsidiary's payoff that collaboration brings, pushing $s_{L,p}$ to the right of s_L.

In summary, the effect of the tax cut is twofold. First, it reduces the tax cost associated with inducing collaboration, and second, it alleviates the internal struggle by making collaboration more appealing to the low-tax subsidiary. Therefore, the MNC's response to the tax cut depends on how the tax cut changes the MNC's tradeoff between tax savings and inducing collaboration. The model predicts that the MNC increases capital allocated to the high-tax subsidiary when the profitability of the collaborative project is high enough to be worth inducing after the tax cut, but not high enough to be worth inducing before. However, contrary to conventional wisdom, the MNC optimally allocates less capital to the high-tax subsidiary when the efficient project is worth inducing both before and after the tax cut.

Next, I consider a tax cut from a high-tax country that applies only to the efficient project. In Europe, some countries have adopted a patent-box regime that taxes income from innovation-related activities at a significantly lower rate than from other corporate income, and there has been a lobbying effort in Canada and the U.S. to introduce a similar program. In the model, the efficient project would qualify for this type of tax reduction because the project involves innovation. In the general rate reduction, the defensive project also qualifies for the tax cut. However, it may not qualify for the patent-box regime because a project that a subsidiary can complete alone (the defensive project) may not involve innovation.

Suppose that the high-tax country reduces its tax rate $\tau + h$ to $\tau + p$, but only the efficient project qualifies. The defensive project thus remains taxed at $\tau + h$. The following corollary characterizes the optimal allocation after this specific tax reduction.

Proposition 4.

The optimal allocation $(\lambda_p^{H*}, \lambda_p^{L*})$ after the specific tax reduction is characterized by:

1. $(\lambda_p^{H*}, \lambda_p^{L*}) = (0, \lambda)$ if $\gamma > \beta$
2. $(\lambda_p^{H*}, \lambda_p^{L*}) = (0, \lambda)$ if $\gamma < \frac{p}{2(1-\tau)-p}\beta$
3. $(\lambda_p^{H*}, \lambda_p^{L*}) = (\lambda - s_{L,p}, s_{L,p})$ if $\frac{p}{2(1-\tau)-p}\beta < \gamma < \beta$, where

$$s_{L,p} = \frac{(1-\tau-p)(\beta+\gamma)}{(2(1-\tau)-p)\beta - p\gamma} \cdot \lambda$$

Note that the optimal allocation is the same optimal allocation as in the case of a general rate reduction by the high-tax country. The first case corresponds to the first-best case when the tax-minimization strategy does not preclude collaboration. The MNC allocates all capital to the low-tax subsidiary, and the two collaborate on the efficient project. This is true regardless of whether there is a tax cut and whether the tax cut is general or specific.

For cases two and three, the MNC trades off the benefit of having the two subsidiaries collaborate on the efficient project against the tax cost associated with it. The tax cost arises because capital allocated to the high-tax subsidiary is taxed at a higher rate, but the headquarters will allocate capital to the high-tax subsidiary only if the two subsidiaries collaborate on the efficient project. It follows that the tax cost is solely determined by the tax rate differential between the two subsidiaries on the efficient project. In other words, the tax cut applied on the efficient project alone reduces the tax cost of inducing collaboration, and whether there is a corresponding tax cut on the defensive project is irrelevant.

V. Empirical Setting and Testable Hypotheses

The model predicts that when a high-tax country undertakes a tax cut, an MNC could decrease, increase, or maintain the capital allocated to the high-tax subsidiary. The response differs depending on how valuable collaborating on the efficient project is to the firm. To formulate a testable hypothesis, I use the patent-box regime as my empirical setting.

The patent-box regime drastically reduces taxes on innovation-related activities. This is a good setting for testing the theory for several reasons. First, this setting offers a clear identification of the exogenous shock. Unlike corporate tax reductions that occur gradually for most countries, a patent-box regime offers a drastic tax cut on the income earned. Second, patenting activities are more likely to involve innovation, an identifiable project investment, and collaboration (Castellani, Castellani, and Zanfei 2006, Singh and Fleming 2010, Zhang and Tang 2017), so the capital allocation on patenting activities closely resembles the project-based allocation in the model. Furthermore, the co-inventor information in the patent filing data reveals information on collaborations. Finally, one of the objectives of the patent-box regime is to attract capital investment and increase innovative activities. Testing the prediction in this setting contributes to the discussion on the intended and unintended consequences of this policy tool.

All patent-box regimes include a favorable tax rate on innovation-related activities, but the type of activities that qualify for the favorable treatment differ across countries.[4] One important difference is whether the regime has a "nexus" requirement that grants the favorable tax rate only if the patent involves local research and development activities. My model considers a situation where both subsidiaries are active in the project, so on the surface, it may suggest that the model's prediction applies only to countries that have the "nexus" requirement. However, a closer look into the motivation behind this requirement would suggest otherwise.

Among the European countries that have implemented the patent-box regime, the nexus requirement is common among low-tax jurisdictions and uncommon among high-tax jurisdictions. This suggests that high-tax countries have little concern over not taking part in the development of patents, likely because they are already the center of research activities. Their primary concern is retaining the resulting intellectual property so they can tax the profit from them. Although many of the highest tax rate countries eventually introduced the "nexus" requirement around 2016, this was mainly to stay compliant with the OECD's recommendations.[5] Because the hypothesis concerns the introduction of the regime by high-tax countries, even though there is no nexus requirement, industries in these countries are likely active in the development of the patent.

[4] For more discussion on the background and details of the patent box regime, refer to Alstadsæter et al. (2015) and Chen et al. (2018). The U.S. Congress by Public Finance also provides an analysis the different features European countries have adopted. https://fas.org/sgp/crs/misc/R44829.pdf

[5] In October 2015, the OECD published a recommendation as part of the BEPS initiative that recommends countries with patent-box regimes to add the nexus requirement. Although this recommendation mainly targets tax havens that grant favorable tax rates on patents without real activities, many high-tax countries with significant patenting activities still followed.

Hypothesis 1 (H1): After a high-tax county implements a "patent-box" regime, an MNC would reduce capital allocated to the high-tax subsidiaries, when collaborating on the innovative project yields high profitability.

VI. Research Design, Data and Sample

Empirical Model

The implementations of the patent-box regime at different times by different countries assign observations into treatment and control groups. This setting more closely resembles a random assignment because both the implementation and its timing are exogenous to the firms. Furthermore, because countries implement the regime at different times, it is a stronger setting than a single-event quasi-experiment.

I use a difference-in-differences design to test the model predictions. The difference-in-differences design "account[s] for unobserved differences between treatment and control firms and to adjust observed changes for the treatment firms by concurrent changes that are also experienced by the control firms" (Daske et al. 2008, 1105). In my empirical setting, because countries implement the patent-box regime at different times, the difference-in-difference term captures the main effect of being a treatment country and a post-change year. Following the design in Amiram, Bauer, and Frank (2018), the country-industry fixed effects account for intrinsic differences between the treatment and control groups, and the year-fixed effects account for the differences experienced by both groups over time.[6] I implement this design with the following equation.

[6] The standard difference-in-differences design is common among studies that utilize an exogenous shock that is a single event, such as the mandatory adoption of the IFRS (Daske et al. 2008, Landsman, Maydew, and Thornock 2012). As discussed in Meyer (1995) and Bertrand, Duflo, and Mullainathan (2004) and implemented in Amiram, Bauer, and Frank (2018), when treatment occurs at different times, fixed effects are used in place of the *Treatment* and *Post* terms in the standard design. This is sometimes referred to as the "staggered difference-in-differences design." A drawback is that the parallel trend assumption cannot be tested because the treatment occurs at different times. Amiram, Bauer, and Frank (2018) use simulation to address the concern somewhat. They also use a placebo

$$Resources_{I,c,t} = \beta_0 + \beta_1 TreatPost_{I,c,t} + \beta_2 Gamma_{i,t} + \beta_3 Gamma_{I,t} * TreatPost_{I,c,t} + ContryIndustryFE + YearFE \quad + TimeVariant\ Controls$$

The dependent variable is the amount of resources projects in country c have in year *t*. The ideal test would examine the allocation within an MNC group for each project, following the model's setup. With this level of data being unavailable, I aggregate at the country-industry level with the following two approaches. The first approach aggregates by patent classification, and the second approach aggregates by the industry of the enterprise. Thus, the dependent variable $Resources_{I,c,t}$ captures resources from projects across industry *I* within country *c* in year *t*.

The difference-in-differences term, $TreatPost_{c,t}$, equals 1 for observations in country *c* that has the patent-box regime in year *t*. The explanatory variable $Gamma_{I,t}$ is the profitability of collaboration of industry I in year *t*, a proxy for the model's construct γ. Like the model, I assume this profitability is a constant amount across countries. Therefore, after aggregating by industry, $Gamma_{I,t}$ is industry-specific and county-independent.

The coefficient β_1 captures the treatment effect of the "patent-box" regime on resources. Although H1 offers no prediction on this term, prior research suggests that "patent-box" regimes on average attract more resources, and a positive β_1 would be consistent with prior literature. The coefficient β_2 captures the relationship between resources and $Gamma_{I,t}$ before the patent-box is implemented. The prior literature does not offer any prediction on the relation between resources and collaboration. The coefficient β_3 on the interaction term between $Gamma_{I,t}$ and $TreatPost_{c,t}$ captures how the "patent-box" regime changes the relationship between resources and collaboration, and H1 predicts a negative β_3. To see this prediction, consider a project with a

test where they assign the control countries a random year of treatment and find no effect. I could implement a similar test to strengthen the inference from the staggered D-in-D design.

given value of *Gamma* and compare its resources before and after the regime. The theory predicts that the resources on the project would decrease if *Gamma* is high and would increase if *Gamma* is low, resulting in a decrease in the slope with respect to *Gamma*.[7]

The difference-in-differences design is a powerful design because it controls for the intrinsic differences among observations. To further strengthen the inference, I include a set of time-variant country and industry characteristics that could affect resources in a country-industry-year and the environment that fosters collaboration.

I focus on the European Union (EU) countries because most countries that have adopted the patent-box regime are in Europe. By the end of 2017, 13 members of the EU had adopted the regime. Furthermore, the geographical proximity and common guidelines shared among EU countries make them more comparable than countries outside of the EU.

H1 applies in a situation when a high-tax country adopts the patent-box regime, so identifying the high-tax countries is important to testing the prediction. In the model, whether a subsidiary is "high-tax" is in relation to the subsidiary of the same MNC. Because I am testing the hypothesis at the industry-country level, I use the corporate tax rate of the country. I restrict my sample to EU countries with the highest corporate tax rates to maximize the power of the test. Countries with moderate tax rates may be "high" or "low" for any project collaboration decision.

Data Sources

I obtain patent data from the European Patent Office (EPO) Linked Open EP Data and the PATSTAT database, which allows an easier extraction of the EPO data. As each patent application moves further along the process, the EPO database creates a record for each stage the application enters. I collect the patent filing information at the application date, which is the

[7] Because the prediction of H1 concerns the slope change rather than an intercept change, an interaction model is more suitable than a sub-sample cross-sectional test.

earliest date that the patent application enters the process. This ensures that the application is counted only once as the patent moves further in the process.

Each patent application record contains the following information: the relevant industries that the patent belongs to, a list of all inventors and their locations, a list of all applicants and their locations, and a description of the patent. The EPO, as with other patent-granting organizations around the world, follows the International Patent Classification (IPC) code maintained by the World Intellectual Property Organization (WIPO). The database covers patents with complete information from 1978 to 2017.

I collect data from the Business Enterprise Research and Development (BERD) database that the OECD maintains.[8] First, I collect information about R&D expenditures incurred by enterprises. I collect the R&D expenditure data in the OECD universal monetary unit to ensure that the measuring units are comparable among observations.[9] Second, I collect the number of full-time equivalent research personnel employed by enterprises. The data further segregates research personnel into researchers and other personnel.

Construction of Key Variables

My first type of dependent variable aggregates capital within enterprises from each country-industry using the OECD BERD database. The OECD uses the International Standard Industrial Classification (ISIC), so the country-industry observation is by ISIC industry. The first dependent variable *Total_RD* is the total R&D expenditure. Total expenditure is then segregated by the type of cost and by the source of funding.[10] I construct my second dependent variable

[8] The OECD provides other alternative resource measures that are less directly related to R&D such as the foreign direct investment (FDI) and the total fixed asset by industry and country.
[9] The conversion uses the rate of each corresponding year or the rate of a fixed year 2010. I collect the data using each year’s conversion rate to account for fluctuations in purchasing power.
[10] The sources of funding are business enterprises, government, other national sources, and funds from abroad; and the type of costs are labor costs, other current costs, and capital expenditures.

RD_FA as the amount of total R&D expenditures that are from abroad. While *Total_RD* reflects capital allocated to subsidiaries from domestic or foreign headquarters, *RD_FA* reflects capital allocated to those in a different jurisdiction than the headquarters. The third dependent variable *Personnel* is the number of full-time equivalent research personnel employed by enterprises in each country-industry during year *t*. Because the number of research personnel is a proxy for capital allocation, I include both researchers and non-researchers to capture the total resources available. Both the R&D expenditures and R&D personnel can take large values, so I transform these variables by taking the natural logarithm of the raw measures.

The second type of dependent variable aggregates projects from each country-industry using the EPO patent database. *Num_Patents* is the sum of all patents filed in year *t* with industry classification *I* that involve at least one inventor from country *c*. While the first set of variables are measures of input, *Num_Patents* is a measure of output and is a less direct measure of capital resources.[11] The number of patents registered in each industry-year can take large values, so I transform the variable by taking the natural logarithm of the raw measure.

To attribute a patent to a country, one could use either the inventor's location or the applicant's location. While the applicant's location reflects the location of ownership, the inventor's location reflects the location of activity. An applicant is the legal owner of the patent and is entitled to the use or the royalties for the use of the patent, whereas the inventor must participate in the development of the patent. As discussed in Toh and Polidoro (2013), it is a legal requirement of the firm to list all parties that have participated in the development of the patent as inventors. On the other hand, the subsidiary can be the legal owner of a patent that is

[11] With the assumption that for any country-industry i-c, the number of patents produced (output) in year t is proportional to the amount of resources (input) it has in year t, I infer the unobservable input from the observable output. There could be a lag in the input-output transformation process, and the output in the current year may reflect the input of a prior year. In untabulated analysis, I use the one-year forward *Num_Patents* as an alternative dependent variable and find results that are qualitatively the same.

developed elsewhere within the corporate group, and its location may differ from the inventor's location.[12]

I construct *Num_Patents* using the inventor's location because it accurately captures the location of the innovative activity. This is important in applying the theory in this empirical setting. In the model, the capital allocated to the subsidiaries is invested into real activities, so it is important that the measure of capital resources captures real activities. In this empirical setting, some firms may take advantage of the low tax rate on patent-related income by simply changing the location of ownership without changing the location of development. Some studies argue that a "patent-box" regime facilitates this behavior and promote shifting taxable income without shifting real activities (Karkinsky and Riedel 2012, Griffith, Miller, and O'Connell 2014, 2010, Ernst and Spengel 2011, Bradley, Dauchy, and Robinson 2015, Böhm et al. 2015, Alstadsæter et al. 2015).[13] My research question is distinguished from the extant literature by studying research activity changes that are real, and the inventor's location is more appropriate for my purpose.[14]

The main variable that the theory offers to explain the differential treatment effects of the regime is the profitability of the collaborative project relative to the non-collaborative project. The literature on collaborations provides some insights into measuring collaborations. Some studies have surveyed business directors, academic researchers, and other research staff about their experiences and perspectives on collaboration (Thomson, Perry, and Miller 2007, Mâsse et al. 2008, Sanders 2007). Other studies have constructed archival measures using the co-author information from publication data or the co-inventor information from patent filing data

[12] While the applicant is usually an entity (a subsidiary), the inventor is usually an individual. The implicit assumption is that the country of the inventor is the same as the country of the subsidiary that employs the inventor.
[13] When countries do not have the "nexus" requirement, firms may qualify for the patent rate without having local R&D activities in the "patent-box" jurisdiction. This is sometimes referred to as "paper-shifting."
[14] Two concurrent studies examine the real effect of the regime in different contexts with different measures. Chen et al. (2018) use affiliate-level data to examine paper-income-shifting behavior and whether there are corresponding changes in total assets. Schwab and Todtenhaupt (2019) use patents granted and proprietary firm-level R&D expenditure data to study the relocation of real activities regarding the "nexus" requirement.

(Beaudry and Schiffauerova 2011, Balconi, Breschi, and Lissoni 2004, Bornmann 2017). One common measure of the extent of collaboration is the ratio of collaborated (or co-authored) projects to the total number of projects (Parish, Boyack, and Ioannidis 2018, Kahn 2017, Toh and Polidoro 2013). More advanced measures capture other aspects of collaboration by analyzing various features of the collaborators' network (Newman 2004, 2001, Abbasi, Hossain, and Leydesdorff 2012, Hou, Kretschmer, and Liu 2008, Fleming, Mingo, and Chen 2007).

In the model, *Gamma* is assessed by the firm for each project. While the inherent profitability on each collaborative project is not observable, with patent data, I can observe the extent of collaboration at the industry level. Following Toh and Polidoro (2013) and with the assumption that highly collaborative industries on average are more profitable at collaborations, I construct *Gamma* as the number of collaborated patents divided by the total number of patents filed in year t with industry classification I.[15] Again, I construct this measure using inventor rather than applicant information because Toh and Polidoro (2013), Fleming, Mingo, and Chen (2007), and Singh and Fleming (2010) claim that the co-inventor information is a reliable measure of the collaboration efforts undertaken.

The fixed effects in this design control for all the effects due to differences in characteristics that are time invariant. To further strengthen the inference, I control for a set of time-variant country and industry characteristics. For country characteristics, I first control the country-year's GDP and its growth, because countries and time periods with more productivity are more likely to be research centers and have resources allocated to R&D activities. These country-years may also provide better environments that foster collaboration. Next, I control a country-year's long-term interest rate as a proxy of investment environment that could promote

[15]For the sample that uses the OECD data, I manually match the ISIC industry to the IPC industries by reviewing the detailed industry descriptions.

R&D activities and collaboration. Finally, I control the tax incentives on R&D provided in the form of R&D credits outside of the patent-box regime. Although these other tax incentives do not occur concurrently with the patent-box regimes, they could affect R&D resources. For industry characteristics, I control for the total production output for each country-industry, where available, as a proxy for size. Larger country-industries generally have more resources and employ more people, which may lead to more research.

Sample and Descriptive Statistics

Table 1 summarizes the corporate tax rates, patent-box related information, and patenting activities for each country. Except for France and Hungary, which implemented the regime in 2001 and 2003, respectively, all other patent-box countries implemented it after 2006. To identify the high-tax countries to test H1, the model calls for a comparison of the corporate tax rate right before the implementation of the regime. Because the implementation time differs across countries, there is no single timeframe to determine the tax rate right before the implementation. I first use the 2006 corporate tax rate, because 2006 is right before the first group of countries implemented the regime around the 2007 and 2008 period. I then use the average tax rate between 2006 and 2010 as a second basis for comparison. I choose the 2006 to 2010 timeframe because the second wave of implementation occurred right after 2010.

A country is generally considered a high-tax country if its corporate tax rate is at or above 30%. In examining changes in corporate tax rate among OECD countries, Clausing (2007) finds that the corporate tax rate among OECD countries averages around 30% and that a 33% tax rate is associated with the highest corporate tax revenue. This statistic is consistent with the descriptive statistics in Simone, Klassen, and Seidman (2017), who study income-shifting behavior within an MNC when the affiliate has losses. In their study, the corporate tax rate has a median of 30% and a 75-percentile of 33%, indicating that the tax rate for most European countries falls below 33% for most of the years. Furthermore, in a stylized example that illustrates two high-tax affiliates of the same tax rate, Dharmapala (2014) uses a corporate tax rate of 30%.

Selecting countries with a 2006 corporate tax rate at or above 30% generates a list of 12 countries. I then validate against the list generated using the average tax rate between 2006 and 2010 and drop the Netherlands and Greece because their corporate tax rates fall significantly below 30% after 2006. I then drop Malta and Luxembourg from the list of high-tax countries for two reasons. First, as discussed earlier, the scenario captured in the theoretical model best matches countries with significant patenting activities. Malta has very little patenting activity, and, while Luxembourg has some patenting activities, they are not very significant. Second, both Malta and Luxembourg are generally considered tax havens. Despite the high stated corporate tax rate, many regimes are in place for companies to circumvent and obtain a much lower effective tax rate.[16] Although the OECD's 2000 list of tax havens does not include these two countries, more recent development on what constitutes a tax haven generally list them as such.[17] Excluding these two countries, I obtain a final list of six high-tax countries.

[16] For example, although Malta's stated corporate tax rate is 35%, if a Maltese subsidiary is set up in a way that avoids being domiciled in Malta (a corporation can be a resident of Malta but not domiciled even with permanent establishment), then although profits taxable in Malta are initially subject to a 35% tax rate, the double-taxation treaty refunds 30% of the taxes when the profits dividend up. This effectively levies a 5% tax rate on the Maltese subsidiary.

[17] The development on what constitutes a tax haven has moved from a simple definition by corporate tax rate (as used in the OECD's 2000 list) to a much more complex definition that considers profit-shifting opportunities (as in Zucman et al. 2018) and incentive to attract foreign direct investment (as in Hines 2010). This development is consistent with the heightened concern in recent years about aggressive profit-shifting strategies that the tax law in some countries enables. This article offers a brief discussion on the history of tax havens (http://www.historyandpolicy.org/policy-papers/papers/history-of-tax-havens)

Table 2 provides a summary of patenting activities for each of the 24 IPC industries from the second layer of the IPC industry tree.[18] I use this layer of industry definition because it provides enough observations within each country-industry while ensuring the industries are not too highly aggregated. From these, I exclude four industries (Combinatorial Technology under Chemistry, Nanotechnology under Operations, Nucleonics under Physics, and Weapons and Blasting under Engineering) from the sample for two reasons. First, activities under these industries are highly regulated, and a tax rate change may not be enough to overcome the regulatory considerations that determine where patents are developed. Second, these industries have very low patenting activities, measured as the total number of patents registered in an industry over the sample period, perhaps consistent with them being highly regulated.

Table 3 provides description for the sample associated with each dependent variable. Panel A presents the sample by year and Panel B the sample size by country. Column (1) describes the *Num_Patents* sample that constructs the country-industry observation using the IPC industry definition. This sample is balanced with 1,920 observations from 6 countries, 20 IPC industries and 16 years over the sample period from 2001 to 2016. Although the EPO covers patent data for earlier years, the sample starts with 2001 because the control variables using OECD data are available since 2001. The sample ends in 2016 because 2018 does not have complete information and some high-tax countries introduced the nexus requirement in their regimes after 2017, following one of the OECD's recommendation under the BEPS project.

Columns (2) to (4) describe the sample using the three resource measures computed with the OECD BERD data. The start of the database is 2007, and the last year with available data is

[18] The broad IPC category H: Electricity has no nodes in the second layer, so I create two nodes on the second layer based on the definition provided in the third layer. Over 40% of the patents filed under Electricity relate to communication technology, so I grouped these patents into a separate category: Communications. The remaining patents are grouped as Other electronic technology.

2014, so the sample period is much shorter. In addition, it does not have data for Belgium. This results in a much smaller sample size. Furthermore, in Panel B, the number of observations varies across countries, suggesting that this data might not be complete for all countries.

Table 4 provides summary statistics of the sample associated with each of the four dependent variables. Around half of the observations are subject to the favorable tax rate under the "patent-box" regime. The sample using total R&D expenditure yields the smallest sample and has a slightly higher percentage of observations in the treatment group. The percentage of collaborated patents averages to about 50% and ranges between 30% to 70%, indicating that firms choose to collaborate on patents 50% of the time with variation among industries. The average of the implied tax subsidy rate ranges from 15% to 23% across the four samples, suggesting that other tax credits subsidize 15 to 23 cents for each additional dollar spent on R&D. The long-term interest rate ranges from below 1% to above 5%, consistent with the fluctuations in economic conditions over the years across countries. Panels B to D report the summary statistics of the country-industry production output in addition to the country-level control variables.[19]

Table 5 reports the Pearson pairwise correlation. In all four samples, the main explanatory variable *Gamma* has little correlation with TreatPost and other variables, suggesting that there is no systematic relationship between *Gamma* and other factors that influence resources. The variable TreatPost by construction will increase over time as more countries start adopting the "patent-box" regime in later years. Therefore, it will correlate with control variables that also increase or decrease over time. It negatively correlates with GDP and long-term interest

[19] I do not include the country-industry production in the regression using Num_Patent because the country-industry level measure can only be obtained for the OECD sample that uses the ISIC industry. Although each ISIC industry can be matched to an IPC classification, it is not so the other way around, as some IPC industries do not have any corresponding ISIC industry. Restricting to only matched IPC industries would significantly reduce the sample size.

rate and positively correlates with the implied tax subsidy rate. The correlations are especially high in Panels B and C with the implied tax subsidy rate. By construction, the implied tax subsidy rate on R&D does not account for the incentives provided in the "patent-box" regime. To alleviate concern that the "patent-box" regime somehow changes this rate, I verify that there is not a jump in the implied tax subsidy rate around the implementation of the "patent-box" regime within sample countries.

VII. Results

Table 6 reports the main results using each of the dependent variables. Panel A reports the result using *Num_Patents* as the dependent variable, and column (1) reports the result from the difference-in-differences design with fixed effects and no additional controls. Consistent with the prior literature that finds a general increase in innovation following a patent-box regime, the coefficient on *Num_Patents*, β_1, is positive and significant at the 1% level. Consistent with the theory's prediction, the coefficient on the interaction term between *TreatPost* and *Gamma* is negative and significant at the 1% level, suggesting that resources decrease after the "patent-box" regime for firms with higher profitability of collaboration. The magnitudes of the coefficient are smaller, but the results are qualitatively unchanged after including the control variables. As expected, the coefficient on GDP is positive and significant, suggesting that countries with larger economic development are more likely to host R&D activities and participate in patent development.

While there is no prediction on the baseline relationship between *Gamma* and resources, the relationship seems to depend on the resource measure used. The coefficient on Gamma is positive and marginally significant only when using the research personnel measure.

Panels B to D report the results using the resource variables from OECD. Column (1) reports the result of the difference-in-differences design with fixed effects and no additional control. Column (2) reports the result with additional country-level control variables that proxy for the size of country's economy and the overall economic condition. Column (3) reports the result with an additional country-industry level control that proxies for size. Finally, Column (4) reports the result with both country-level and country-industry level controls. Because the country-industry level controls capture variation not only in a country a but also in an industry, they are stronger than country-level controls: column (3) provides a more conservative estimate than column (2). Finally, because column (4) includes both sets of controls, it provides the most conservative estimates. Consistent with the theory's prediction, the coefficient on the interaction between *TreatPost* and *Gamma* is negative and significant across all specifications. Overall, the results from all specifications across the four different dependent measures are consistent with the theory's prediction that when a high-tax country implements the "patent-box" regime, firms allocate less resources if they face high profitability on collaboration.

VIII. Conclusion

I examine the interaction between international tax-planning and the managerial objective of coordinating knowledge-sharing among subsidiaries in an MNC's capital allocation among its international subsidiaries. Prior studies find that a firm's international transfer pricing decision faces a tradeoff between tax minimization and providing appropriate managerial incentive in the production setting. This study is the first to examine whether a tradeoff exists in the capital allocation decision in the context of inducing subsidiaries to collaborate and share expertise. The model shows that the tax-planning opportunity creates a tax cost for inducing collaboration, so the MNC faces a tradeoff. In addition, I consider how capital allocation changes after a high-tax jurisdiction introduces a tax cut. The model predicts that the MNC's response to the tax cut depends on the value of internal collaboration. I utilize an exogenous tax event, the patent-box regime, to test the model's prediction. The results show that research activities and resources are lower among country-industries that value internal collaboration, whereas research activities and resources increase among country-industries that have a low value of internal collaboration, consistent with the model's prediction.

The study contributes to the literature by examining how an MNC balances its tax-planning objective with its other managerial objectives such as promoting the sharing of subsidiary-specific resource, in its capital allocation among its international subsidiaries. The managerial challenge of inducing subsidiaries to collaborate on new projects is one that is well-documented in the international business literature, but not yet incorporated in the international tax-planning literature. This study contributes to the policy debate on the implications of a tax cut with respect to attracting capital investment and promoting innovative activities. It highlights the importance of considering a firm's managerial objectives in assessing the impact of a tax policy, an aspect that has not been examined in prior literature.

Appendix I. Theory Results Stated with a General Sharing Rule ω

Proposition 1 Stated with a General ω

1. (D, D) is a sub-game perfect equilibrium for any λ^H, λ^L.
2. Let

$$s_H = \frac{(1-\tau)(\beta+\gamma)}{\left(\frac{1}{1-\omega}(1-\tau-h)+h\right)\beta+h\gamma}\cdot\lambda$$

$$s_L = \frac{(1-\tau-h)(\beta+\gamma)}{\left(\frac{1}{\omega}(1-\tau)-h\right)\beta-h\gamma}\cdot\lambda$$

(a) For $\omega \geq \frac{1}{2}$,

i. If $\gamma > \frac{\omega}{1-\omega}\beta$, (E,E) is a sub-game perfect equilibrium for any λ^H, λ^L

ii. If $\frac{1-\omega}{\omega}\beta < \gamma < \frac{\omega}{1-\omega}\beta$, (E,E) is a sub-game perfect equilibrium if and only if

$$\lambda^H \leq s_H$$

iii. If $\gamma < \frac{1-\omega}{\omega}\beta$, (E,E) is a sub-game perfect equilibrium if and only if

$$\lambda^H \leq s_H \; and \; \lambda^L \leq s_L$$

(b) For $\omega \leq \frac{1}{2}$,

i. If $\gamma > \frac{1-\omega}{\omega}\beta$, (E,E) is a sub-game perfect equilibrium for any λ^H, λ^L

ii. If $\frac{\omega}{1-\omega}\beta < \gamma < \frac{1-\omega}{\omega}\beta$, (E,E) is a sub-game perfect equilibrium if and only if

$$\lambda^L \leq s_L$$

iii. If $\gamma < \frac{\omega}{1-\omega}\beta$, (E,E) is a sub-game perfect equilibrium if and only if

$$\lambda^H \leq s_H \; and \; \lambda^L \leq s_L$$

Proposition 2 Stated with a General ω

The optimal allocation $(\lambda^{H*}, \lambda^{L*})$ is

1. $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma > \frac{1-\omega}{\omega}\beta$.
2. $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma < \frac{(1-\omega)h}{1-\tau-(1-\omega)h}\cdot\beta$.
3. $(\lambda^{H*}, \lambda^{L*}) = (\lambda - s_L, s_L)$ if $\frac{(1-\omega)h}{1-\tau-(1-\omega)h}\cdot\beta < \gamma < \frac{1-\omega}{\omega}\beta$.

Lemma 1 Stated with a General $\boldsymbol{\omega}$

The optimal allocation $(\lambda_p^{H*}, \lambda_p^{L*})$ after the general tax reduction is characterized by:

1. $(\lambda_p^{H*}, \lambda_p^{L*}) = (0, \lambda)$ if $\gamma > \frac{1-\omega}{\omega}\beta$.
2. $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma < \frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta$.
3. $(\lambda^{H*}, \lambda^{L*}) = (\lambda - s_{L,p}, s_{L,p})$ if $\frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta < \gamma < \frac{1-\omega}{\omega}\beta$, where

$$s_{L,p} = \frac{(1-\tau-p)(\beta+\gamma)}{\left(\frac{1}{\omega}(1-\tau)-p\right)\beta - p\gamma} \cdot \lambda$$

Proposition 3 Stated with a General $\boldsymbol{\omega}$

1. When $\gamma > \frac{1-\omega}{\omega}\beta$ or $\gamma < \frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta$, $\lambda_p^{H*} = \lambda^{H*}$.
2. When $\frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta < \gamma < \frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta$, $\lambda_p^{H*} > \lambda^{H*}$.
3. When $\frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta < \gamma < \frac{1-\omega}{\omega}\beta$, $\lambda_p^{H*} < \lambda^{H*}$.

Proposition 4 Stated with a General $\boldsymbol{\omega}$

The optimal allocation $(\lambda_p^{H*}, \lambda_p^{L*})$ after the **specific** tax reduction is characterized by:

1. $(\lambda_p^{H*}, \lambda_p^{L*}) = (0, \lambda)$ if $\gamma > \frac{1-\omega}{\omega}\beta$.
2. $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma < \frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta$.
3. $(\lambda^{H*}, \lambda^{L*}) = (\lambda - s_{L,p}, s_{L,p})$ if $\frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta < \gamma < \frac{1-\omega}{\omega}\beta$, where

$$s_{L,p} = \frac{(1-\tau-p)(\beta+\gamma)}{\left(\frac{1}{\omega}(1-\tau)-p\right)\beta - p\gamma} \cdot \lambda$$

Appendix II. Proofs

Proof of Proposition 1 with General ω

1. Fixing subsidiary H's choice of D, we compare $\pi_L^{D,E}$ with $\pi_L^{D,D}$. By $\theta > \gamma$, we have

$$\pi_L^{D,E} = (1-\tau)(\beta+\gamma-\theta)\lambda^L < (1-\tau)\beta\lambda^L = \pi_L^{D,D}$$

Fixing L's choice of D, we can similarly show that $\pi_H^{E,D} < \pi_H^{D,D}$. Therefore, (D,D) is a sub-game perfect equilibrium.

2. Without loss of generality, assume $\omega \geq \frac{1}{2}$.

(a) If $\gamma > \frac{\omega}{1-\omega}\beta$.

Fixing subsidiary H's choice of E, we compare $\pi_L^{E,E}$ with $\pi_L^{E,D}$. First, because $\omega \geq \frac{1}{2}$, we know $\frac{\omega}{1-\omega}\beta \geq \frac{1-\omega}{\omega}\beta$. Furthermore, because $\gamma > \frac{\omega}{1-\omega}\beta$, we have $\gamma > \frac{1-\omega}{\omega}\beta$. Rearranging this inequality, we get $\omega(\beta+\gamma) > \beta$. Therefore,

$$\begin{aligned}\pi_L^{E,E} &= \omega\big((1-\tau-h)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L\big)\\ &\geq (1-\tau)\omega(\beta+\gamma)\lambda^L > (1-\tau)\beta\lambda^L = \pi_L^{E,D}\end{aligned}$$

Fixing subsidiary L's choice of E, we can similarly show that $\pi_H^{E,E} > \pi_H^{D,E}$. Here, because $\gamma > \frac{\omega}{1-\omega}\beta$, we have $(1-\omega)(\beta+\gamma) > \beta$. Therefore,

$$\begin{aligned}\pi_H^{E,E} &= (1-\omega)\big((1-\tau-h)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L\big)\\ &\geq (1-\tau-h)(1-\omega)(\beta+\gamma)\lambda^H > (1-\tau-h)\beta\lambda^H = \pi_H^{D,E}\end{aligned}$$

Therefore, (E,E) is a sub-game perfect equilibrium when $\gamma > \frac{\omega}{1-\omega}\beta$.

(b) If $\frac{1-\omega}{\omega}\beta < \gamma < \frac{\omega}{1-\omega}\beta$.

Fixing subsidiary H's choice of E, because $\gamma > \frac{1-\omega}{\omega}\beta$, $\omega(\beta+\gamma) > \beta$, we still have

$$\pi_L^{E,E} > \pi_L^{E,D}$$

Fixing subsidiary L's choice of E, we compare $\pi_H^{E,E}$ with $\pi_H^{D,E}$, where

$$\pi_H^{E,E} = (1-\omega)\big((1-\tau-h)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L\big)$$
$$\pi_H^{D,E} = (1-\tau-h)\beta\lambda^H$$

Recall that the total resources available for allocation is the total initial endowment between two subsidiaries, so we can substitute $\lambda^L = \lambda - \lambda^H$ into $\pi_H^{E,E}$. Solving $\pi_H^{E,E} \geq \pi_H^{D,E}$ gives $\lambda^H \leq s_H$, where

$$s_H = \frac{(1-\tau)(\beta+\gamma)}{\left(\frac{1}{1-\omega}(1-\tau-h)+h\right)\beta+h\gamma} \cdot \lambda$$

(c) If $\gamma \leq \frac{1-\omega}{\omega}\beta$

Fixing subsidiary H's choice of E, we compare $\pi_L^{E,E}$ with $\pi_L^{E,D}$, where

$$\pi_L^{E,E} = \omega\big((1-\tau-h)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L\big)$$

$$\pi_L^{E,D} = (1-\tau-h)\beta\lambda^H$$

Again, we can substitute $\lambda^H = \lambda - \lambda^L$ into $\pi_L^{E,E}$. Solving $\pi_L^{E,E} > \pi_L^{E,D}$ gives $\lambda^L \leq s_L$, where

$$s_L = \frac{(1-\tau-h)(\beta+\gamma)}{\left(\frac{1}{\omega}(1-\tau)-h\right)\beta-h\gamma} \cdot \lambda$$

Fixing subsidiary L's choice of E, we can similarly show that $\pi_H^{E,E} \geq \pi_H^{D,E}$ when $\lambda^H \leq s_H$.

Proof of Proposition 2 with General ω

I apply a backward induction to this sequential game. Proposition 1 shows that there are two possible sub-game perfect equilibria to the subsidiaries' game. Next, I will derive the optimal allocation for the headquarters that maximizes total payoff. The form of total payoff depends on the sub-game equilibrium, so let

$$\pi^{E,E} = (1-\tau-h)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L$$

be the total payoff to the MNC group associated with strategy profile (E,E), and

$$\pi^{D,D} = (1-\tau-h)\beta\lambda^H + (1-\tau)\beta\lambda^L$$

be the total payoff to the MNC group associated with strategy profile (D,D). Next, I will show that given the subsidiaries' actions, the total payoff increases with λ^L.

Claim 1: $\pi^{E,E}$ and $\pi^{D,D}$ are increasing in λ^L.

Proof of Claim 1: rewrite $\pi^{E,E}$ and $\pi^{D,D}$ as functions of λ^L by substituting $\lambda^H = \lambda - \lambda^L$,

$$\begin{aligned}\pi^{E,E} &= (1-\tau-h)(\beta+\gamma)(\lambda-\lambda^L) + (1-\tau)(\beta+\gamma)\lambda^L \\ &= (1-\tau-h)(\beta+\gamma)\lambda + h(\beta+\gamma)\lambda^L \\ \pi^{D,D} &= (1-\tau-h)\beta(\lambda-\lambda^L) + (1-\tau)\beta\lambda^L \\ &= (1-\tau-h)(\beta+\gamma)\lambda + h\beta\lambda^L\end{aligned}$$

Both $\pi^{E,E}$ and $\pi^{D,D}$ are linear functions with a positive coefficient in λ^L.

Claim 2: $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma > \frac{1-\omega}{\omega}\beta$.

Proof of Claim 2: By Proposition 1, (E,E) is an equilibrium with any resource allocation λ^H, λ^L. By Claim 1, the headquarters maximizes total payoff by allocation all resources to subsidiary L. If $\gamma < \frac{1-\omega}{\omega}\beta$, (E,E) is no longer an equilibrium with the headquarters allocates all resources to subsidiary L. Recall that (D,D) is always an equilibrium, but (E,E) is an equilibrium only if the headquarters uses resource allocation to induce it. The following claim establishes the condition under which (E,E) is worthwhile to induce and the optimal resource allocation in such a case.

Claim 3:

1. $(\lambda^{H*}, \lambda^{L*}) = (0, \lambda)$ if $\gamma < \frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta$.
2. $(\lambda^{H*}, \lambda^{L*}) = (\lambda - s_L, s_L)$ if $\frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta < \gamma < \frac{1-\omega}{\omega}\beta$.

Proof of Claim 3: Whether it is worthwhile for the headquarters to induce (E,E) depends on how its best payoff compares to the best payoff under (D,D). By Claim 1 and Proposition 1, if the headquarters choose to induce (E,E), the maximum payoff is achieved by taking the upper bound of λ^L, which is s_L. If the headquarters does not induce (E,E), the maximum payoff under (D,D) is achieved by allocating all resources to subsidiary L. Comparing these two payoffs, inducing (E,E) is desirable when

$$\pi^{E,E}|_{\lambda^L = s_L} \geq \pi^{D,D}|_{\lambda^L = \lambda}$$

Solving this gives $\gamma \geq \frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta$.

Proof of Proposition 3 with General ω

1. (a) If $\gamma > \frac{1-\omega}{\omega}\beta$, the headquarters optimally allocates all resources to subsidiary L, and (E,E) is an equilibrium. Together with Proposition 2.1, we have $\lambda^{H*} = \lambda_p^{H*} = 0$.

   (b) If $\gamma < \frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta$, we have that $\lambda_p^{H*} = 0$. One can check that $\frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta < \frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta$ when $0 < p < h$, so by Proposition 2.2, we have $\lambda^{H*} = 0 = \lambda_p^{H*}$.
2. When $\frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta < \gamma < \frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta$, it is not worthwhile to induce (E,E) before the tax rate reduction, but the tax reduction makes it worthwhile. Therefore, $\lambda^{H*} = 0$, but $\lambda_p^{H*} = \lambda - s_{L,p} > 0$.
3. When $\frac{(1-\omega)h}{1-\tau-(1-\omega)h} \cdot \beta < \gamma < \frac{1-\omega}{\omega}\beta$, by Proposition 2.3, we can compute

$$\lambda^{H*} = \lambda - s_L = \frac{(1-\tau)\big((1-\omega)\beta - \omega\gamma\big)}{(1-\tau-\omega h)\beta - \omega h\gamma}\lambda$$

$$\lambda_p^{H*} = \lambda - s_{L,p} = \frac{(1-\tau)\big((1-\omega)\beta - \omega\gamma\big)}{(1-\tau-\omega p)\beta - \omega p\gamma}\lambda$$

Their difference

$$\lambda^{H*} - \lambda_p^{H*} = \frac{(1-\tau)\big((1-\omega)\beta - \omega\gamma\big)(\beta+\gamma)\omega(h-p)\lambda}{\big((1-\tau-\omega h)\beta - \omega h\gamma\big)\big((1-\tau-\omega p)\beta - \omega p\gamma\big)} > 0$$

Proof of Proposition 4 with General ω

The proof follows essentially the same procedure as the proof of the Proposition 2. I apply a backward induction to this sequential game when there is a special tax cut. First, consider the sub-game perfect equilibria. Without loss of generality, assume $\omega \geq \frac{1}{2}$.

Claim 1:

1. (D, D) is a sub-game perfect equilibrium for any λ^H, λ^L.
2. Let

$$s_{H,p} = \frac{(1-\tau)(\beta+\gamma)}{\left(\frac{1}{1-\omega}(1-\tau-h)+h\right)\beta + p\gamma}\cdot\lambda$$

$$s_{L,p} = \frac{(1-\tau-p)(\beta+\gamma)}{\left(\frac{1}{\omega}(1-\tau)-p\right)\beta - p\gamma}\cdot\lambda$$

(a) If $\gamma > \frac{\omega}{1-\omega}\beta$, (E,E) is a sub-game perfect equilibrium for any λ^H, λ^L

(b) If $\frac{1-\omega}{\omega}\beta < \gamma < \frac{\omega}{1-\omega}\beta$, (E,E) is a sub-game perfect equilibrium if and only if

$$\lambda^H \leq s_{H,p}$$

(c) If $\gamma < \frac{1-\omega}{\omega}\beta$, (E,E) is a sub-game perfect equilibrium if and only if

$$\lambda^H \leq s_{H,p} \text{ and } \lambda^L \leq s_{L,p}$$

The proof of Claim 1 is almost identical to the proof of Proposition 1, except that $\pi_H^{E,E} = (1-\omega)\big((1-\tau-p)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L\big)$ now reflects the high-tax subsidiary's payoff from collaboration after the tax cut. Therefore, in solving the equation $\pi_H^{E,E} = \pi_H^{D,E}$, the solution $s_{H,p}$ also reflects the tax cut.

Next, I derive the optimal allocation by the headquarters that maximizes total payoff. Let $\pi^{E,E}$ and $\pi^{D,D}$ be the total payoff to the MNC group associated with strategy profiles (E,E) and (D,D), where

$$\pi^{E,E} = (1-\tau-p)(\beta+\gamma)\lambda^H + (1-\tau)(\beta+\gamma)\lambda^L$$

$$\pi^{D,D} = (1-\tau-h)\beta\lambda^H + (1-\tau)\beta\lambda^L$$

Similar to the proof of Proposition 2, one can show that $\pi^{E,E}$ and $\pi^{D,D}$ are increasing in λ^L.

When $\gamma > \frac{1-\omega}{\omega}\beta$, (E,E) is an equilibrium with any resource allocation strategy, so the tax minimizing allocation does not preclude (E,E) being an equilibrium. The headquarters optimally allocates all resources to subsidiary L.

When $\gamma < \frac{1-\omega}{\omega}\beta$, following the Claim 3 in the proof of Proposition 3, inducing (E,E) is desirable when

$$\pi^{E,E}|_{\lambda^L = s_{L,p}} \geq \pi^{D,D}|_{\lambda^L=\lambda}$$

Solving this inequality, I obtain the condition $\gamma \geq \frac{(1-\omega)p}{1-\tau-(1-\omega)p} \cdot \beta$, which is exactly the same as it is in Proposition 3.

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Figures

Figure 1. Model Timeline

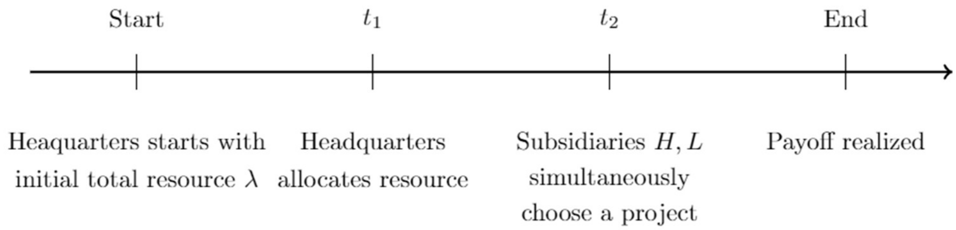


Figure 2. Comparison of subsidiary L's payoff given subsidiary H's choice of E

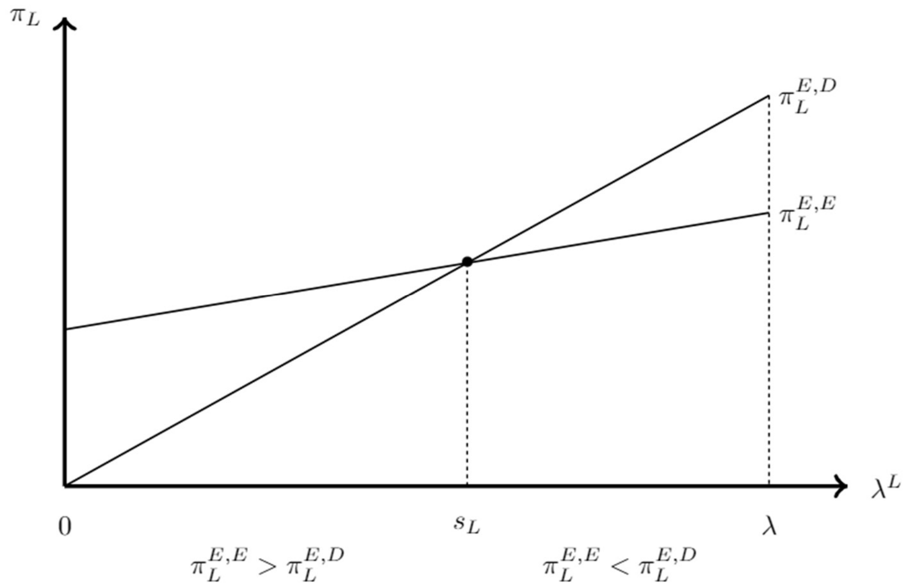
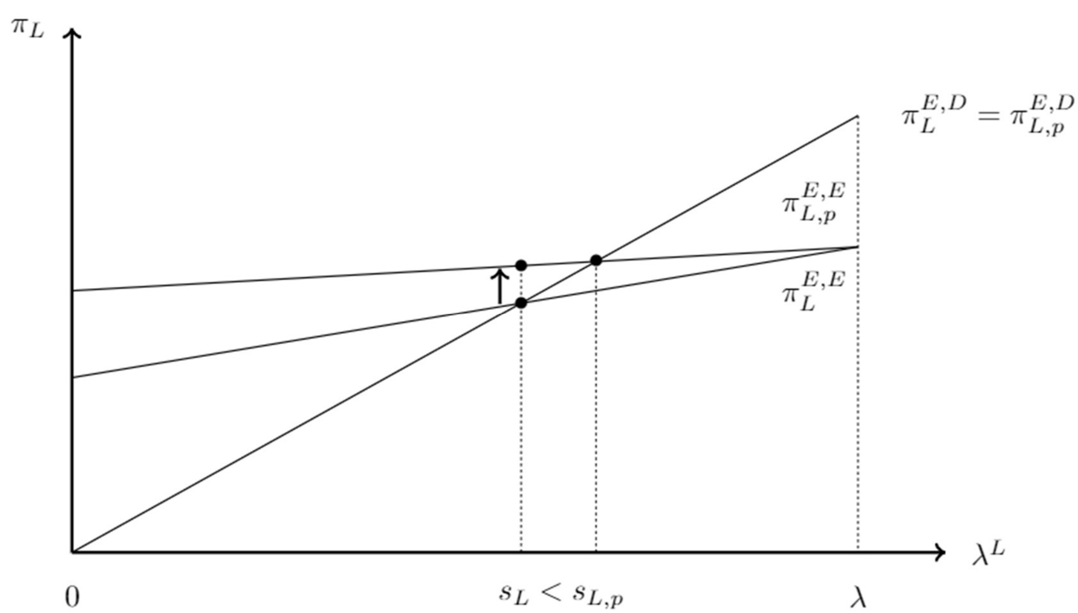


Figure 3. Payoff to subsidiary L before and after tax rate change



Tables

Table 1. Summary of Country Characteristics

Country Name	Corporate Tax Rate (2006)	Corporate Tax Rate (Avg. 2006-2010)	IP-Box country	Year of Implementation	IP Tax Rate	Patenting Activities
Germany	38.34	33.01				566,809
Italy	37.25	33.74	Yes	2015	15.7	107,058
Malta	35.00	35.00	Yes	2010 (terminated 2016)	0	206
Spain	35.00	31.50	Yes	2008	12	40,677
Belgium	33.99	33.99	Yes	2007	5.1	43,260
France	33.33	33.33	Yes	2001	17.1	213,882
United Kingdom	30.00	29.20	Yes	2013	10	169,964
Luxembourg	29.63	29.21	Yes	2008	5.84	2,849
Netherlands	29.60	26.32	Yes	2007	5	90,194
Greece	29.00	25.60				2,941
Denmark	28.00	25.60				32,089
Norway	28.00	28.00				15,654
Sweden	28.00	27.32				73,675
Portugal	27.50	25.50	Yes	2014	15.75	3,051
Finland	26.00	26.00				39,420
Austria	25.00	25.00				43,383
Slovenia	25.00	22.20				2,866
Czech	24.00	21.60				5,439
Estonia	23.00	21.60				760
Switzerland	21.30	19.77	Yes	2011	8.8	86,488
Croatia	20.00	20.00				1,273
Poland	19.00	19.00				8,124
Slovakia	19.00	19.00				1,489
Iceland	18.00	16.80				960
Hungary	16.00	16.60	Yes	2003	10.3	5,761
Romania	16.00	16.00				1,605
Bulgaria	15.00	11.00				954
Latvia	15.00	15.00				662
Lithuania	15.00	16.00				569
Macedonia	15.00	11.40				71
Ireland	12.50	12.50	Yes	1973	6.25	10,134
Bosnia	10.00	10.00				154
Cyprus	10.00	10.00	Yes	2012	2.5	343
Serbia	10.00	10.00				359
Montenegro	9.00	9.00				17

Note: the corporate income tax rate is taken from the KPMG corporate tax table. The IP-box information is from various online articles and policy discussions related to the regime[20]. The patenting activities of a country is the number of patents with at least one inventor from that country over 1998-2016.

[20] See footnote 7 for more details and the following link contains the KPMG corporate tax table: https://home.kpmg/xx/en/home/services/tax/tax-tools-and-resources/tax-rates-online/corporate-tax-rates-table.html

Table 2 Summary of IPC Industry Patenting Activities

IPC Class	Industry	#Patent	# with 2 or more inventor
A: Human Necessities	Agriculture	24,685	11,700
	Food and Tabaco	20,529	11,597
	Personal or Domestic Articles	42,334	15,074
	Health, Life, Amusement	148,296	83,586
B: Operations	Separating, mixing	46,520	25,471
	Shaping	81,067	39,376
	Printing	14,737	7,496
	Transport	148,249	66,482
	Nanotechnology	1,695	1,065
C: Chemistry	Chemistry	184,784	131,028
	Metallurgy	18,213	11,434
	Combinatorial Technology	51	38
D: Textile and Paper	Textile	17,578	9,605
	Paper	7,081	4,028
E: Fixed Construction	Building	55,504	18,324
	Drilling and Mining	10,378	3,970
F: Engineering	Engine	58,881	28,935
	General Engineering	55,671	25,171
	Lightning and Heating	42,807	20,155
	Weapon and Blasting	5,405	2,368
G: Physics	Instruments	229,424	118,988
	Nucleonics	2,213	1,254
H: Electricity	Communication	114,848	63,917
	Other Electronics	133,858	71,175

Note: Patents include those filed with the EPO over the sample period. The industry definition follows the International Patent Classification (IPC) code maintained by the World Intellectual Property Organization (WIPO). The number of patents is measured by the total number of patents registered in each industry over the sample period. The number of collaborated patents equals the total number of patents that involve at least 2 inventors.

Table 3 Sample Description

Panel A: Sample size by year				
	(1) *Num_Patent*	(2) *Total_RD*	(3) *RD_FA*	(4) *Personnel*
2001	120			
2002	120			
2003	120			
2004	120			
2005	120			
2006	120			
2007	120	61	128	115
2008	120	98	130	179
2009	120	97	149	183
2010	120	97	126	187
2011	120	128	158	189
2012	120	96	128	182
2013	120	163	162	183
2014	120	98	98	126
2015	120			
2016	120			
Total	1,920	838	1,079	1,344

Panel B: Sample size by country				
	(1) *Num_Patent*	(2) *Total_RD*	(3) *RD_FA*	(4) *Personnel*
Belgium	320			178
France	320	226	228	217
Germany	320	64	121	224
Italy	320	66	261	251
Spain	320	225	220	224
United Kingdom	320	257	249	250
Total	1,920	838	1,079	1,344

Note: *Num_Patent* is the total number of patents registered in each country-industry and is constructed using the EPO patent database. *Total_RD* is the total R&D expenditure from all enterprises within a country-industry. *RD_FA* is the portion of the total R&D expenditure with the source of fund from abroad. *Personnel* is the total number of research employee employed by enterprises within a country-industry. These three variables are constructed with data from the OECD's BERD database on R&D activities by business enterprises.

Table 4 Summary Statistics

Panel A: Summary statistics for the test using Num_Patent as DV								
Variable	N	mean	sd	p5	p25	p50	p75	p95
Num_Patent	1920	5.303	1.496	2.740	4.304	5.389	6.304	7.659
TreatPost	1920	0.427	0.495	0	0	0	1	1
Gamma	1920	0.510	0.091	0.327	0.458	0.516	0.564	0.680
Log GDP	1920	14.293	0.704	12.867	14.039	14.546	14.80	15.08
Implied Tax Subsidy	1920	0.149	0.167	-0.030	-0.020	0.100	0.335	0.450
Real GDP Growth	1920	1.222	1.986	-2.928	0.491	1.613	2.503	3.723
Interest Rate	1920	3.541	1.346	0.840	2.665	4.010	4.452	5.187
Panel B: Summary statistics for the test using Total_RD as DV								
Variable	N	mean	sd	p5	p25	p50	p75	p95
Total_RD	838	4.939	2.145	0.103	3.559	5.079	6.561	8.228
TreatPost	838	0.6158	0.4867	0	0	1	1	1
Gamma	838	0.5305	0.0836	0.3805	0.4715	0.5271	0.5798	0.6936
Log GDP	838	14.656	0.3133	14.124	14.307	14.787	14.867	15.138
Implied Tax Subsidy	838	0.23	0.1696	-0.02	0.09	0.21	0.35	0.44
Real GDP Growth	838	0.313	2.0612	-3.574	-0.999	0.4896	1.9494	2.9476
Interest Rate	838	3.5597	1.0755	1.918	2.6083	3.6244	4.3164	5.4369
Log Industry Production	838	10.874	0.9922	9.4001	10.091	10.747	11.715	12.54
Panel C: Summary statistics for the test using RD_FA as DV								
Variable	N	mean	sd	p5	p25	p50	p75	p95
RD_FA	1079	2.157	2.139	0.000	0.121	1.383	4.028	5.994
TreatPost	1079	0.4764	0.4997	0	0	0	1	1
Gamma	1079	0.5294	0.0842	0.3805	0.4711	0.5247	0.5772	0.6936
Log GDP	1079	14.67	0.2899	14.124	14.569	14.784	14.867	15.138
Implied Tax Subsidy	1079	0.1932	0.1674	-0.02	0.09	0.12	0.35	0.44
Real GDP Growth	1079	0.0576	2.389	-5.482	-1.706	0.5763	1.7112	3.2605
Interest Rate	1079	3.7841	1.0774	1.918	2.8932	4.0357	4.4873	5.4927
Log Industry Production	1079	10.946	0.9629	9.4379	10.197	10.812	11.745	12.54
Panel D: Summary statistics for the test using Personnel as DV								
Variable	N	mean	sd	p5	p25	p50	p75	p95
Personnel	1344	7.110	2.002	3.694	5.943	7.223	8.391	10.204
TreatPost	1344	0.5089	0.5001	0	0	1	1	1
Gamma	1344	0.5309	0.0843	0.3857	0.4711	0.5259	0.5799	0.6936
Log GDP	1344	14.498	0.6057	13.118	14.213	14.689	14.882	15.138
Implied Tax Subsidy	1344	0.1714	0.1596	-0.02	0.09	0.12	0.35	0.44
Real GDP Growth	1344	0.2525	2.308	-4.247	-1.05	0.5763	1.7983	3.2605
Interest Rate	1344	3.6387	1.1121	1.57	2.7433	3.9017	4.3637	5.4369
Log Industry Production	1344	10.764	1.1328	8.8614	10.041	10.723	11.626	12.553

Note: Panel A contains the descriptive statistics of the dependent variable, the main explanatory variable, and control variables for observations in the regression that uses the natural log of the number of patents filed in industry i that include at least one inventor from country c in year t as the dependent variable. Gamma is the percentage of collaborated patents in industry i year t. Panels B to D provide the descriptive statistics of the three R&D resources variables using the R&D activity data by the OECD. All three variables take the natural log of their respective raw measure. Panel A provides summary statistics of the time-variant country characteristics as additional control variables. Panels B to D provide summary statistics of these country-level controls and country-industry level controls.

Table 5 Pearson Correlation

Panel A: Correlation table for the test using *Num_Patent* as DV							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Num_Patent							
(2) TreatPost	-0.13						
(3) Gamma	0.10	0.04					
(4) Log GDP	0.52	-0.14	0.03				
(5) Implied Tax Subsidy	-0.27	0.49	0.02	-0.09			
(6) Real GDP Growth	-0.04	-0.09	-0.01	-0.10	0.05		
(7) Interest Rate	-0.16	-0.30	-0.09	-0.19	-0.06	-0.13	

Panel B: Correlation table for the test using *Total_RD* as DV								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Total_RD								
(2) TreatPost	0.00							
(3) Gamma	0.10	0.00						
(4) Log GDP	0.06	-0.42	-0.02					
(5) Implied Tax Subsidy	-0.01	0.83	-0.02	-0.40				
(6) Real GDP Growth	0.04	-0.06	0.00	0.50	-0.22			
(7) Interest Rate	-0.08	0.19	-0.05	-0.55	0.26	-0.42		
(8) Log Industry Production	0.05	-0.08	0.05	0.23	-0.09	0.11	-0.17	

Panel C: Correlation table for the test using *RD_FA* as DV								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) RD_FA								
(2) TreatPost	-0.11							
(3) Gamma	0.01	0.02						
(4) Log GDP	0.12	-0.37	-0.02					
(5) Implied Tax Subsidy	-0.13	0.84	0.00	-0.40				
(6) Real GDP Growth	0.04	0.07	0.02	0.35	-0.04			
(7) Interest Rate	-0.10	-0.07	-0.04	-0.48	0.05	-0.32		
(8) Log Industry Production	0.11	-0.13	0.06	0.23	-0.13	0.05	-0.10	

Panel D: Correlation table for the test using *Personnel* as DV								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Personnel								
(2) TreatPost	-0.12							
(3) Gamma	0.13	0.01						
(4) Log GDP	0.26	-0.53	-0.02					
(5) Implied Tax Subsidy	-0.05	0.77	-0.01	-0.18				
(6) Real GDP Growth	0.02	0.02	0.01	0.13	-0.12			
(7) Interest Rate	-0.08	0.04	-0.05	-0.24	0.17	-0.34		
(8) Log Industry Production	0.22	-0.30	0.09	0.51	-0.12	0.05	-0.11	

Table 6 Main Results

Panel A: Regression using *Num_Patent*			
Variable	Pred	Num_Patent	Num_Patent
TreatPost	+	0.364***	0.296***
		(4.43)	(3.61)
Gamma		-0.116	-0.118
		(-0.55)	(-0.57)
TreatPost * Gamma	-	-0.461**	-0.447**
		(-2.95)	(-2.91)
Log GDP			0.575***
			(5.58)
Implied Tax Subsidy			-0.234**
			(-2.85)
Real GDP Growth			-0.0298***
			(-4.82)
Interest Rate			0.00282
			(-0.24)
Country-Industry Fixed Effects		Yes	Yes
Year-Fixed Effects		Yes	Yes
N		1920	1920
Adjusted R^2		0.978	0.979

Panel B: Regression Using *Total_RD*					
Variable	Pred	Total_RD	Total_RD	Total_RD	Total_RD
TreatPost	+	1.483**	1.584**	1.209**	1.393**
		(2.94)	(2.93)	(2.38)	(2.57)
Gamma		1.977	1.925	1.776	1.790
		(1.37)	(1.34)	(1.24)	(1.25)
TreatPost * Gamma	-	-2.088*	-2.000*	-1.774*	-1.793*
		(-2.24)	(-2.13)	(-1.90)	(-1.92)
Log GDP			-0.203		-0.379
			(-0.29)		(-0.53)
Implied Tax Subsidy			1.395		1.586
			(1.32)		(1.50)
Real GDP Growth			-0.0135		-0.00925
			(-0.30)		(-0.20)
Interest Rate			-0.134*		-0.109
			(-1.92)		(-1.56)
Log Industry Production				0.883***	0.749**
				(3.24)	(2.65)
Country-Industry Fixed Effects		Yes	Yes	Yes	Yes
Year-Fixed Effects		Yes	Yes	Yes	Yes
N		838	838	838	838
Adjusted R^2		0.932	0.931	0.931	0.932

Panel C: Regression Using *RD_FA*					
Variable	Pred	RD_FA	RD_FA	RD_FA	RD_FA
TreatPost	+	1.523*	1.527*	1.493*	1.504*
		(2.23)	(2.16)	(2.16)	(2.11)
Gamma		2.938*	2.928*	2.923*	2.918*
		(1.80)	(1.79)	(1.79)	(1.79)
TreatPost * Gamma	-	-3.044**	-2.871*	-3.011**	-2.848*
		(-2.41)	(-2.24)	(-2.38)	(-2.22)
Log GDP			-1.201*		-1.211*
			(-1.90)		(-1.91)
Implied Tax Subsidy			-0.491		-0.483
			(-0.85)		(-0.83)
Real GDP Growth			0.0186		0.0183
			(0.47)		(0.46)
Interest Rate			-0.0249		-0.0220
			(-0.44)		(-0.39)
Log Industry Production				0.101	0.0919
				(0.32)	(0.28)
Country-Industry Fixed Effects		Yes	Yes	Yes	Yes
Year-Fixed Effects		Yes	Yes	Yes	Yes
N		1079	1079	1079	1079
Adjusted R^2		0.867	0.867	0.867	0.867

Panel D: Regression Using *Personnel*					
Variable	Pred	Personnel	Personnel	Personnel	Personnel
TreatPost	+	1.168***	0.914**	1.014***	0.793**
		(4.02)	(3.09)	(3.52)	(2.69)
Gamma		1.441*	1.327*	1.354*	1.253*
		(2.27)	(2.10)	(2.15)	(2.00)
TreatPost * Gamma	-	-1.634**	-1.254*	-1.471**	-1.137*
		(-3.04)	(-2.31)	(-2.77)	(-2.12)
Log GDP			0.313		0.184
			(1.24)		(0.73)
Implied Tax Subsidy			-0.794**		-0.742**
			(-3.05)		(-2.88)
Real GDP Growth			0.0257*		0.0274*
			(1.81)		(1.95)
Interest Rate			-0.0305		-0.0115
			(-1.45)		(-0.54)
Log Industry Production				0.621***	0.565***
				(5.35)	(4.71)
Country-Industry Fixed Effects		Yes	Yes	Yes	Yes
Year-Fixed Effects		Yes	Yes	Yes	Yes
N		1344	1344	1344	1344
Adjusted R^2		0.972	0.971	0.971	0.972

Note: The unit of observation is at country-industry-year level. TreatPost is the difference-in-difference variable that equals 1 if country c has implemented the patent-box regime in year t. Gamma is the profitability of collaboration computed using inventor information and is the ratio of collaborated patents to total patents. Column 1 reports the result using the log of the number of patents filed in year t in industry I that includes at least one inventor from country c as the dependent variable. Column 2 reports the result using the log of total R&D expenditure for industry i, country c, and year t using

OECD data. Column 3 reports the result using the log of total R&D expenditure with the source of fund from aboard. Column 4 reports the result using the log of the total number of R&D personnel. The model includes year-fixed effects and country-industry effects to control for individual observation characteristics and time trend. The sample period is from 1996 to 2018 and includes only highest-tax countries that have corporate tax rates above 30%: Germany, Italy, Spain, Belgium, France, and UK. The model predicts a negative interaction between the difference-in-differences variable and Gamma.

*, **, and *** indicate statistical significance at 5%, 1%, and 0.1% levels. All tests are one-sided.