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Stephan Worack

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# **Indigenous Invention, M&A, and International Collaboration: Essays on China's Rise to Innovation**

Stephan Worack

*Thèse pour l'obtention du grade de Docteur  
de l'Université Paris 1 Panthéon-Sorbonne en Sciences Economiques*

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# Résumé

Le développement économique de la Chine est sans doute l'un des sujets les plus fascinants et les plus importants de l'économie mondiale actuelle. En l'espace de quarante ans et depuis l'ouverture et les réformes économiques de la Chine à la fin des années 1970, la Chine est passée d'un pays fermé et rétrograde sur le plan économique à la deuxième économie mondiale.

Sous l'impulsion d'une croissance tirée par l'investissement et les exportations, la Chine est devenue une économie manufacturière de "low-tech" très performante dans les années 1990 et au début des années 2000. Les réformes économiques continues et ses avantages comparatifs dans les biens intensifs en travail peu qualifié ont soutenu des niveaux de croissance élevés pendant plus de deux décennies et ont fait de la Chine l'atelier du monde au début du millénaire. Dès lors, les politiques et les investissements se sont multipliés pour tenter de transformer le pays en une économie fondée sur la connaissance et l'innovation. En effet, la Chine vise non seulement à devenir un pays de haute technologie doté d'une industrie manufacturière de pointe du niveau de celle des pays développés, mais aussi le leader mondial de l'innovation d'ici le milieu du siècle.

L'inquiétude sous-jacente, une contrainte majeure croissante et une des motivations motrices de cette entreprise est le "piège du revenu moyen" (Woo, 2012; Worldbank, 2013). La théorie et l'histoire économique suggèrent que les pays en développement peuvent rester bloqués à un certain niveau de revenu par rapport aux principales économies du monde. Le risque est que le pays en développement se retrouve dans une telle

situation, incapable d'une part de concurrencer les économies à faible revenu et à bas salaires pour les produits manufacturés et, d'autre part, avec des économies avancées pour des innovations hautement qualifiées, lucratives, et innovantes pour le monde. (Asia Development Bank, 2011).

Un des moyens le plus crucial pour surmonter le piège du revenu intermédiaire et de soutenir une croissance dynamique et l'innovation sous ses formes diverses et variées (Worldbank, 2015, 2013). Pour cela, la Chine a déployé des efforts massifs pour installer un système d'innovation national, renforcer sa capacité d'invention et pour créer une dynamique de rattrapage en matière d'innovation. Cela s'est déjà manifesté avec succès dans de nombreuses industries telles que les technologies de l'information et de la communication et les énergies renouvelables, et a été mesuré par divers indicateurs d'innovation (Fu, 2015; Li and Zhang, 2018).

En effet, si l'on considère la question du développement technologique du point de vue des chiffres purs, la Chine a enregistré une augmentation remarquable et rapide des indicateurs d'intrants et d'extrants couramment utilisés en recherche et développement (R&D) depuis le début des années 2000. Parallèlement aux taux de croissance élevés de son PIB, les dépenses de R&D, le personnel scientifique et technologique et l'infrastructure de recherche ont augmenté à un rythme impressionnant. Du côté de la production de R&D, le nombre de brevets déposés des entreprises chinoises a "explosé" (Hu and Jefferson, 2009; Hu, 2010). Les brevets en tant que forme la plus connue de droits de propriété intellectuelle ont pour but d'encourager l'activité inventive et de récompenser le titulaire par des récompenses monétaires. En fait, l'office d'État chinois des brevets intellectuels (SIPO) est devenu le plus grand office de dépôt au monde en 2014. Pourtant, dans tous les grands offices de brevets étrangers, tels que l'office des brevets et des marques des États-Unis (USPTO) et l'office européen des brevets (OEB), ainsi que l'Organisation mondiale de la propriété intellectuelle (OMPI), où la protection des brevets est soumise à un examen plus rigoureux, les demandes et les brevets chinois ont également énormément augmentés (Kesan et al., 2016; van Dijk et al., 2015; Wunsch-

Vincent et al., 2015). En Europe, le géant chinois des télécommunications Huawei est devenu le premier déposant de demandes de brevet à l'OEB en 2017 et un nombre croissant d'autres entreprises technologiques chinoises telles que Xiaomi, BYD et Tencent y déposent leurs inventions. Ainsi, un nombre croissant d'entreprises chinoises semblent de plus en plus capables d'inventer des technologies.

Toutefois, la majorité des entreprises chinoises ne disposent toujours pas d'une technologie de production avancée. Comme l'explique (Fu et al., 2016), le manque de technologie de production avancée est une différence clé entre un pays en développement et un pays développé. Pour le pays en développement, la croissance de la productivité pourrait être réalisée de deux façons,

- i) l'adoption de technologies existantes plus avancées en provenance de l'étranger (par des canaux tels que l'octroi de licences, le commerce international, l'investissement étranger direct, la migration des compétences, la collaboration internationale en matière de recherche, la diffusion des connaissances désincarnées, transfert et diffusion de la technologie par la participation à la chaîne de valeur mondiale) et
- ii) le renforcement des innovations technologiques autochtones.

Cette thèse de doctorat s'articule autour de l'analyse des capacités inventives et innovantes de la Chine et des différents canaux utilisés pour les atteindre. Plus précisément, comme l'indique le titre "Invention autochtone, fusions-acquisitions et collaboration internationale", cette thèse étudie la croissance de la Chine en matière d'innovation. Le premier chapitre, co-écrit avec Ilja Rudyk, explore les politiques d'innovation autochtones de la Chine. Elles sont analysées en fonction de leur capacité à susciter une plus grande appropriation nationale des technologies "stratégiques" que le gouvernement chinois considère comme essentielles pour sa trajectoire nationale et économique à venir. Le deuxième, rédigé en collaboration

avec Anthony Howell et Jia Lin, explore le rôle des fusions et acquisitions transfrontalières chinoises dans la performance de l'innovation nationale. Enfin, le troisième chapitre examine de plus près le rôle de la collaboration internationale dans la qualité des inventions de la Chine à l'étranger. Dans les sections suivantes, ces trois chapitres sont brièvement introduits ainsi que leur contribution à la littérature.

### **L'essor des inventions "autochtones" chinoises : Preuves tirées des données sur les brevets européens**

Après un développement sans précédent pendant près de trente ans, en grande partie boosté par la production et l'exportation de produits manufacturés, la Chine a entrepris des investissements massifs dans la production et l'exportation de produits manufacturés. Ces efforts de grande envergure ont eu pour objectif de changer son moteur de croissance, avec la volonté, à terme, de dynamiser son économie pour davantage l'axer sur les services et l'innovation. Depuis le début du nouveau millénaire, l'innovation domestique, locale et indépendante, est devenue l'une des plus hautes priorités des dirigeants chinois, tant en termes de rhétorique qu'en termes de ressources allouées à la question. Développer des capacités d'innovation indépendantes et réduire la dépendance envers les technologies étrangères représente le cœur de la façon dont les plans de politique d'innovation, les régulations, et les lois sur la propriété intellectuelle ont été façonnées au cours de la dernière décennie (Ahrens, 2010; Chen and Naughton, 2016; Hout and Ghemawat, 2010; Luginbuehl, 2014; Prud'homme, 2012, 2013a). Pour les dirigeants chinois, la possession de technologies clés et la possibilité d'innover de manière indépendante sont essentiels pour la concurrence, le développement et pour un satisfaire un large éventail de facteurs économiques et sociaux, tels que les problématiques environnementales, économiques, et de sécurité nationale.

Deux pierres angulaires et directives de cet objectif primordial sont le *National Medium- and Long-Term Program for Science and Technology De-*

velopment (MLP) promulgués par le Conseil d'Etat en 2006 (The State Council, 2006) et *12th Five-Year National Development Plan of Strategic Emerging Industries* (SEI), publié par le Conseil d'Etat en 2012 (The State Council, 2012) qui énoncent les directives à adopter. L'un de leurs principaux but est d'augmenter la possession de droits de propriété intellectuelle (DPI) dans les classes technologiques ciblées que le gouvernement chinois considère comme essentielles pour le développement futur du pays (Gao, 2015; Hu and Jefferson, 2009; McGregor, 2010; Prud'homme, 2012, 2013a; Serger and Breidne, 2007).

L'objectif du premier chapitre de ma thèse est d'analyser l'effet de ces politiques d'innovation (indigènes) sur les inventions chinoises à l'étranger, notamment en Europe. Nous utilisons les brevets chinois comme indicateur des capacités et des activités d'innovation de la Chine. De plus, mon co-auteur et moi-même nous intéressons à l'effet de ces politiques sur les caractéristiques des inventions déposées dans les domaines ciblés par ces mesures politiques. Des études récentes ont révélé que la qualité des demandes de brevet chinois, tant nationales qu'internationales, a diminué, en raison de politiques chinoises de subventions directes en matière d'innovation et de DPI, tel que pour les brevets internationaux types *Patent Cooperation Treaty* (PCT). (Dang and Motohashi, 2015; Lei et al., 2012; Boeing and Mueller, 2015, 2016).

Plus précisément, nous utilisons une approche fondée sur la technique d'estimation des écarts dans les différences pour analyser i) si la Chine possède de plus en plus ses inventions indigènes dans les domaines technologiques étrangers ciblés en examinant l'évolution de la "possession" chinoise des brevets en opposition à la "possession" étrangère des brevets qui incluent un ou plusieurs inventeurs chinois et ii) s'il y a eu des changements observables dans le processus d'élaboration des caractéristiques de ces inventions qui refléteraient un changement qualitatif. À cette fin, nous construisons et nous nous appuyons sur un ensemble de données composées de toutes les demandes de brevet pour des technologies inventé ou co-inventé par un résident chinois déposées au office européen des brevets

(OEB) en utilisant les données d'information sur les brevets de l'OEB. De plus, nous créons une table de concordance entre les technologies stratégiques ciblées dans les sous-catégories MLP (SEI respectivement) et les brevets à 4 chiffres de la Classification internationale des brevets (CIB4) grâce à l'outil de catégorisation de l'organisation des biens, IPCCAT. Afin d'évaluer l'impact sur les brevets nous utilisons différents indicateurs de qualité des brevets, fournis par l'OCDE dans la Patent Quality Database, une base de données de qualité, qui est fusionnée à notre propre base de données.

De toute évidence, les activités chinoises de dépôt de brevets en Chine et à l'étranger ont connu un essor considérable depuis le début du millénaire comme le démontrent plusieurs articles académiques et les études de plusieurs chercheurs aux principaux offices de dépôts des brevets, y compris le Office Européen des brevets (OEB), le *United States Patent and Trademark Office* (USPTO) et l'Office mondial de la propriété intellectuelle (OMPI) (van Dijk et al., 2015; Eberhardt et al., 2017; Hu and Jefferson, 2009; Kesan et al., 2016; Wunsch-Vincent et al., 2015). Ces études sont basées sur les dépôts de brevet chinois, c'est-à-dire les demandes de brevet dont le premier déposant est un résident chinois. Une autre façon d'examiner les activités inventives et de dépôts brevets d'un pays est d'analyser les éléments suivants: les demandes de brevets qui ont été inventées et déposées par les résidents d'un pays. Ici aussi, les activités chinoises ont connu une augmentation spectaculaire. En effet, les inventions chinoises enregistrées en tant que propriété intellectuelle en Europe par le biais de demandes de brevet Euro Direct et Euro PCT auprès d'inventeurs chinois à l'Office Européen des brevets entre 1995 et 2013 ont "explosé".<sup>1</sup>

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<sup>1</sup>Lorsqu'ils déposent une demande de dépôt de brevet en Europe, les demandeurs peuvent choisir entre i) le dépôt auprès des offices nationaux de propriété intellectuelle (voie nationale), ii) le dépôt auprès de l'OEB d'un brevet européen (Euro Direct) pour tous ou une partie des États contractants de la Convention sur le brevet européen (CBE) (voie européenne) ou iii) le dépôt à l'OEB d'une demande internationale de brevet en tant qu'office récepteur et le choix ultérieur facultatif du passage à la phase européenne (Euro PCT/voie internationale) de la demande. La publication d'une telle demande après être entrée dans la phase régionale peut prendre jusqu'à 30 mois.

Le premier chapitre met l'accent sur les (co)inventions d'entités chinoises. En effet, le nombre de demandes de brevet déposées auprès de l'OEB par au moins un inventeur chinois a augmenté à un rythme rapide. La propriété - définie par le premier demandeur - de ces demandes de brevet avec (co)inventions chinoises est au cœur de notre analyse.

Dans ce chapitre, mon co-auteur et moi-même explorons les politiques d'innovation de la Chine au cours des dernières décennies. Nous observons une résurgence et un changement dans la politique industrielle de la Chine avec le développement de politiques d'innovation chinoises qui mettent l'accent de plus en plus sur le développement des capacités nationales et indépendantes (Heilmann and Shih, 2013; Chen and Naughton, 2016). L'autosuffisance de la Chine en matière de science et de technologie et une limitation de la dépendance à l'égard de la technologie étrangère d'ici 2020 doivent être réalisées par l'innovation "autochtone" (Cheng and Huang, 2016; Luginbuehl, 2014). Cette politique met l'accent sur l'autonomie et le contrôle stratégique de l'innovation en Chine et signale une implication accrue du gouvernement dans les processus d'innovation depuis sa première formulation dans le MLP (Lazonick et al., 2016). Les directives générales des politiques d'innovation autochtones sont le MLP et le SEI. Ils partagent le principal objectif de développer et d'accroître l'appropriation des DPI dans des classes technologiques ciblées que le gouvernement chinois considère comme essentielles pour le développement futur du pays (Gao, 2015; Hu and Jefferson, 2009; McGregor, 2010; Prud'homme, 2012, 2013a; Serger and Bredine, 2007; Cheung et al., 2016).

A cet égard, les politiques susmentionnées et les lignes directrices et directives propres à leur secteur d'activité comprennent une combinaison d'instruments tels que les marchés publics et les catalogues de produits autochtones connexes, les fonds de brevets, les subventions aux brevets, les normes technologiques nationales, le soutien direct à la recherche et au développement et les politiques fiscales préférentielles visant à assurer une base solide de propriété intellectuelle nationale dans les industries stratégiques (McGregor, 2010; Prud'homme, 2012; Cheung et al., 2016;

USITC, 2011, 2010; USCBC, 2013). Elles ont été promulguées et mises en œuvre aux niveaux central et infranational, c'est-à-dire provincial et municipal.<sup>2</sup>

Toutefois, toutes ces analyses se limitent seulement à des analyses qualitatives et descriptives et ne mesurent pas spécifiquement l'effet des politiques sur la propriété intellectuelle et les brevets, ni la possession des droits de propriété. A notre connaissance, il n'existe aucune étude qui tente de mesurer empiriquement l'impact et l'efficacité des politiques sur la propriété intellectuelle dans les industries stratégiques chinoises. Notre étude contribue à la littérature sur les politiques d'innovation dans les économies émergentes et à la compréhension du développement technologique de la Chine et des tentatives de rattrapage en particulier.

Dans notre modélisation économétrique, nous utilisons une approche fondée sur la technique d'estimation des écarts dans les différences pour vérifier si la Chine est de plus en plus propriétaire de ses inventions indigènes dans les domaines technologiques ciblés par les politiques. Pour cela, nous examinons les développements en chinois par opposition à la propriété étrangère des brevets impliquant des inventeurs chinois.

Pour toutes nos spécifications, nous trouvons une association positive et significative que la probabilité pour que les Chinois possèdent une (co)invention chinoise appartenant à une sous-classe de technologie (catégorisation en 4 digit, IPC4, de l'OMPI) qui faisait partie du plan de politique ciblée dans le MLP et le SEI augmente à partir de 2012 par rapport aux (co)inventions chinoises qui ne font pas partie des sous-classes visées. Nos résultats indiquent que les diverses mesures prises ont conduit à une augmentation de la propriété chinoise dans les inventions indigènes possédées par les chinois qui ont été favorisées par le MLP and le SEI.

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<sup>2</sup>Pour des examens approfondis et une liste détaillée des documents, lois, articles spécifiques, circulaires, mesures et avis gouvernementaux, provinciaux et municipaux connexes, voir, pour MLP: (Prud'homme, 2012, pp.62-123), (USITC, 2010, pp.95-117), (Cheung et al., 2016, pp.29-37) and for SEI: USCBC (2013), (Cheung et al., 2016, pp.29-37), (Prud'homme, 2012, pp.62-123) and (Prud'homme, 2012, pp.161-225)

C'est en nous fondant sur l'examen de la qualité des brevets, en particulier en Chine, et sur les réflexions théoriques et les résultats empiriques de la littérature économique décrits précédemment que nous développons notre deuxième axe d'investigation. Les données disponibles et l'approche que nous avons choisie nous ont permis d'examiner les effets potentiels des mesures politiques sur différentes caractéristiques et les aspects qualitatifs de ces demandes.

Les inventions brevetées diffèrent grandement par leur qualité (Griliches, 1990; Squicciarini et al., 2013b). Un nombre limité d'études ont évalué la qualité des demandes de brevet chinois, tant au niveau national<sup>3</sup> qu'à l'étranger, en utilisant différentes approches pour évaluer la qualité et la valeur d'un brevet.<sup>4</sup> Très peu d'articles évaluent l'impact des politiques chinoises en matière de brevets sur les brevets délivrés à l'étranger aux entités chinoises. En ce qui concerne la dimension internationale des activités chinoises en matière de brevets et leur qualité, (Thoma, 2013) étudie divers indicateurs de qualité dans les familles de brevets internationaux chinois comme dans les demandes OEB et PCT. L'auteur compare les demandes chinoises et étrangères selon différents indicateurs de qualité tels que le nombre de subventions, le nombre d'oppositions, les rapports de recherche supplémentaires et les décisions de renouvellement à l'OEB. Ses conclusions suggèrent une qualité généralement inférieure des brevets chinois "indigènes", c'est-à-dire par les déposants nationaux, par rapport à ceux des déposants internationaux.

L'étude de Boeing and Mueller (2016, 2015) est l'exception car elle analyse des applications PCT internationales de la Chine et de leur qualité. Les auteurs construisent un nouvel index basé sur les citations des rapports de

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<sup>3</sup>Comme expliqué dans la note de bas de page 11, il existe trois types de "brevets" pouvant être demandés et protégés au SIPO : les brevets d'invention, modèles d'utilité, et brevets de conception. Les modèles d'utilité et les brevets de conception du SIPO n'ayant pas besoin d'un examen approfondi, "(ldots)", il est difficile de déterminer s'ils apportent de la nouveauté et de la valeur". (Dang and Motohashi, 2015, p.5)

<sup>4</sup>Pour un aperçu détaillé de ce que sont les indicateurs de la qualité d'un brevet et comment ils peuvent être utilisés pour rendre compte la qualité des brevets, voir Squicciarini et al. (2013b)

recherche internationale de demandes PCT et montrent que l'introduction de subventions de brevets PCT en Chine a entraîné une baisse de qualité comme mesurée dans les rapports de recherche internationale par *International Search Reports*.

Dans un deuxième axe de recherche, nous nous intéressons aux changements potentiels des caractéristiques et des indicateurs de valeur des inventions chinoises qui pourraient avoir été une conséquence du plan politique du SEI. Le but ici est d'estimer s'il y a eu un effet sur la qualité des inventions dans les technologies stratégiques ciblées par rapport aux technologies non ciblées. Nous utilisons quatre indicateurs distincts, établis dans la littérature qui indiquent la qualité d'un brevet (Squicciarini et al., 2013a). Ce sont le nombre de revendications, le nombre de citations reçues (dans une fenêtre de temps de cinq ans), le nombre de citations antérieures et la taille de la famille des demandes de brevet chinois déposées par des inventeurs et des co-inventeurs chinois. Nous utilisons la même méthodologie que dans le chapitre précédent et utilisons une approche de différence dans les différences. Compte tenu de la nature des données de comptage des différentes variables dépendantes qui déterminent la qualité du brevet, nous avons choisi d'utiliser la technique d'estimation de quasi-vraisemblance de Poisson.

Les résultats pour les deux politiques sont différents. Pour le MLP, nos résultats suggèrent que les demandes de brevet chinois auprès d'inventeurs ou de co-inventeurs chinois dans les technologies ciblées sont d'une qualité inférieure que les technologies non ciblées après la mise en œuvre du MLP. Par contre, aucun effet significatif n'a été trouvé quant à la qualité des applications de brevets, mesurée en nombre de citations reçues et la taille de la famille de l'application.

Pour le SEI, nos résultats suggèrent que les demandes de brevet chinois auprès d'inventeurs ou de co-inventeurs chinois dans les technologies ciblées ont été de meilleure qualité (mesurée en citations en arrière et taille de la famille de l'application) que dans les technologies non ciblées

après la mise en œuvre du SEI. Plus spécifiquement, les inventions dans les technologies ciblées, par rapport aux non ciblées, devraient comporter 7 % de citations antérieures de plus et 7,8 % de primes en ce qui concerne la taille de la famille de l'invention chinoise, après la mise en œuvre du plan SEI.

Finalement, nous trouvons donc des indications que, malgré les critiques formulées à propos de la qualité et de la valeur des inventions chinoises, celles-ci auraient pu s'améliorer après les réformes les plus récentes. Ceci est documenté par le nombre croissant de citations antérieure et de la taille de la famille des technologies ciblées par le SEI par rapport aux technologies non ciblées après sa mise en œuvre.

### **Sortir pour innover davantage chez soi: les effets des investissements directs à l'étranger sur la performance des entreprises chinoises en matière d'innovation sur le marché intérieur**

Ce chapitre, en co-rédaction avec Anthony Howell et Jia Lin, examine les effets des investissements directs chinois à l'étranger, obtenus dans le cadre de fusions ou d'acquisition transfrontalières, sur l'innovation et les performances économiques des sociétés cotées en bourse chinoises. Un nouvel ensemble de données a été construit, permettant d'analyser les effets des fusions et acquisitions transfrontalières sur l'innovation et la performance financière des entreprises chinoises cotées en bourse. Nous nous appuyons sur des techniques d'appariement combinées avec une approche de différence afin d'aider à corriger un éventuel biais de sélection de l'échantillon. Ce chapitre apporte à la littérature sur les fusions et acquisitions transfrontalières en Chine une étude empirique au niveau de l'entreprise et des brevets.

Les investissements directs à l'étranger en provenance de Chine ont fortement augmenté depuis le début des années 2000, ce qui coïncide avec

l'entrée de la Chine à l'Organisation mondiale du commerce (OMC) et le lancement de la stratégie chinoise de "going out". Au début des années 2000, les entreprises chinoises avaient tendance à cibler les pays riches en ressources, principalement en Afrique, afin de garantir un meilleur accès aux ressources naturelles et aux marchés émergents. Cependant, à la suite de la crise financière mondiale, le comportement de la Chine en matière d'ODI s'est radicalement transformé pour cibler les économies développées dans le but de se doter d'actifs stratégiques et de promouvoir une montée en puissance technologique rapide. La majorité des investissements directs chinois à l'étranger ciblant les économies développées consistent principalement en des opérations de fusions et acquisitions. Selon le groupe Rhodium, seulement 9% des investissements directs chinois aux États-Unis s'élevant à 106 milliards de dollars entre 2000 et 2016 découlent de investissements de création (en anglais "greenfield investment") et moins de 5% des investissements directs à l'étranger de 20,6 milliards de dollars dans l'UE au quatrième trimestre de 2016.<sup>5 6</sup>

Il existe une littérature abondante et croissante sur les schémas, les moteurs et les "vagues" d'ODI des économies émergentes (Gammeltoft and Kokko, 2013; Lebedev et al., 2014; Sauvart, 2005; Sauvart et al., 2009). Dans le contexte chinois, des études montrent que le comportement des entreprises chinoises en matière d'ODI repose au moins en partie sur leur quête d'accès aux ressources, aux marchés, au savoir-faire, aux technologies de pointe et aux économies d'échelle et de gamme (Boateng et al., 2008; Buckley et al., 2007; Deng and Yang, 2015). Souvent incités et subventionnés de manière conséquente par le gouvernement chinois, les entités chinoises investissent de plus en plus dans les économies développées à la recherche d'actifs stratégiques et d'une montée en puissance technologique rapide (Amighini et al., 2013; Deng, 2007, 2009; Di Minin et al., 2012; Duysters et al., 2009; Huang and Wang, 2013; Peng, 2012; Rui and Yip, 2008; Spigarelli et al., 2013). Cependant, la plupart de la littérature existante qui attribue un comportement stratégique de recherche d'actifs

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<sup>5</sup>Voir Rhodium Group China Investment Monitor 2017

<sup>6</sup>Voir Rhodium Group EU-China FDI Monitor 2016 4Q Update

au comportement ODI chinois est basée sur des arguments théoriques ou des études de cas individuelles plutôt que sur des preuves empiriques (Deng, 2013).

En outre, la littérature économique traitant de l'impact des M & A sur la performance d'innovation de l'entité issue de la fusion donne des résultats mitigés. Théoriquement, l'effet net des fusions et acquisitions est ambigu. La fusion avec une autre entreprise ou l'acquisition d'une autre entreprise peut avoir divers effets sur les résultats de R&D de l'entité fusionnée. Comme Veugelers (2006) l'explique, les opérations de fusions et acquisitions pourraient, par des raisons d'efficacité et de concurrence dans la R&D ainsi que sur le marché de la production, conduire à une augmentation ou à une diminution des intrants de R&D et de ses performances en raison de l'existence d'économies d'échelle et de gamme, ainsi que de l'augmentation du pouvoir de marché. Des études empiriques portant sur les effets des fusions et acquisitions sur la performance en matière d'innovation ont abouti à des résultats mitigés. Des études antérieures portant sur les effets de fusions et acquisitions sur les performances économiques, telles que la rentabilité, ont également donné des résultats incohérents. Alors que certaines analyses révèlent un impact moyen positif (Healy et al., 1992), d'autres font état de pertes post-fusions et acquisitions dans la performance opérationnelle des entreprises (Bertrand et al., 2013; Yeh and Hoshino, 2002) ou suggèrent des résultats contrastés (Ghosh, 2001; Tuch and O'Sullivan, 2007; Sharma and Ho, 2002).

L'objectif de l'étude dans le chapitre 2 est de combler cette lacune dans la littérature et de faire progresser notre compréhension de la manière dont le comportement des entreprises chinoises en matière de fusions et acquisitions transfrontalières influe sur leurs performances d'innovation ultérieures en Chine. En particulier, nous cherchons à répondre à certaines questions cruciales, à savoir, quand et comment les fusions et acquisitions chinois à l'étranger conduisent aux résultats d'innovation souhaités chez eux. L'étude empirique examine l'impact des fusions et acquisitions transfrontalières chinoises en termes de performance d'innovation

nationale post-transaction au niveau de l'entreprise et par analyse des brevets. L'analyse de cette étude repose sur un nouvel ensemble de données au niveau de l'entreprise construit avec les trois principales sources de données suivantes liées à cette fin.

Nous construisons un nouvel ensemble de données au niveau de l'entreprise qui combine les informations de la base chinoise de données WIND et de la base de données Zephyr de Bureau van Dijk. C'est-à-dire que nous établissons un lien entre les informations commerciales et financières générales, y compris les dépenses de R&D, pour toutes les sociétés cotées sur les marchés boursiers chinois de Shanghai et Shenzhen depuis WIND avec toutes les transactions transfrontalières majoritaires de ces sociétés enregistrées dans la base de données Zephyr. Nous ajoutons ensuite les portefeuilles de brevets d'invention nationaux, y compris les citations et les informations de revendications, des entreprises à l'ensemble de données, en utilisant les informations de brevet publiques de l'Office chinois de la propriété intellectuelle (SIPO). Enfin, nous obtenons des informations sur les brevets dans la base de données INCOPAT, qui fournit toutes les informations publiques sur les brevets collectées par le SIPO, y compris les portefeuilles de brevets d'invention nationaux des entreprises chinoises répertoriées de notre échantillon. En plus du nombre de demandes de brevet d'invention et du nombre de demandes acceptées, INCOPAT fournit également des informations supplémentaires sur les citations et les revendications des brevets individuels. Conformément à la littérature, les informations sur les citations et les revendications peuvent être utilisées pour mesurer la qualité des brevets des entreprises.

Il est reconnu d'emblée que les entreprises qui s'engagent dans les fusions et acquisitions transfrontalières risquent d'être systématiquement différentes de celles qui ne le font pas, ce qui rend difficile l'identification de l'effet causal de la fusions et acquisitions transfrontalières sur l'innovation en raison d'un biais de sélection potentiel. Pour traiter ce problème, les techniques d'appariement du score de propension (PSM) sont combinées à la méthode de différence de différences (PSM-DiD). La stratégie

d'identification PSM-DiD est courante dans la littérature, en partie parce que la procédure d'appariement permet d'assurer la comparabilité des groupes de traitement et de contrôle, tandis que l'estimateur DiD prend en compte l'hétérogénéité ferme non observable dans le temps négligée par PSM. En outre, en raison de certaines critiques récentes à propos de PSM, des techniques de correspondance alternatives sont également utilisées en tant que vérification de la robustesse.

L'approche PSM-DiD s'effectue en deux temps. Dans la première étape, une technique d'appariement du score de propension non linéaire est utilisée pour construire un groupe d'entreprises témoin qui correspond le mieux aux entreprises traitées en fonction de caractéristiques observables. Une liste de covariables est développée afin d'identifier le groupe de contrôle le plus approprié. Les covariables sélectionnées incluent une gamme de variables permettant de contrôler différentes dimensions de la performance des entreprises. Les entreprises du groupe témoin sont appariées au groupe de traitement sur la base de la moyenne de pré-traitement (avant que l'entreprise ne termine sa première fusion et acquisition transfrontalière. Dans une deuxième étape, une méthode de différence dans les différences permet de prendre en compte toute variable temporelle fixée dans le temps et estime l'effet des fusions et acquisitions transfrontalières sur les résultats des entreprises qui se lancent dans des fusions et acquisitions transfrontalières.

Dans notre première estimation, nous estimons via DiD l'impact des fusions et acquisitions transfrontalières sur les efforts d'innovation représentés par l'intensité de la R&D, mesurée par le ratio dépenses de R&D par rapport aux revenus d'exploitation. Les résultats suggèrent que les entreprises ont tendance à s'appuyer sur leur fusions et acquisitions transfrontalières et à acquérir des connaissances externes d'une manière qui complète les dépenses internes consacrées aux activités de recherche. Ensuite, nous étudions les effets des fusions et acquisitions transfrontalières sur la performance des entreprises en matière d'innovation, déterminée par le nombre de demandes de brevets et de brevets nationaux délivrés. Un effet positif

significatif est observé sur le nombre de demandes de brevet. L'effet le plus important est observé l'année de l'achèvement des fusions et acquisitions transfrontalières et, dans les années suivantes, il est quantitativement moins important. En ce qui concerne les effets des fusions et acquisitions transfrontalières sur les brevets délivrés, en revanche, les résultats indiquent que les effets des fusions et acquisitions transfrontalières ne deviennent statistiquement significatifs que deux ans après l'achèvement de la fusions et acquisitions transfrontalières. Cela semble logique intuitivement car les entreprises peuvent s'attendre à un certain délai pour exploiter les connaissances acquises à l'étranger dans de nouvelles connaissances brevetables en Chine. En ce qui concerne le lien des fusions et acquisitions transfrontalières et la qualité des inventions, nos résultats indiquent une amélioration soutenue de la qualité de l'innovation des entreprises, mesurée par les revendications de brevets. Nous trouvons une association positive et significative pendant toutes les années observées après les fusions et acquisitions transfrontalières.

Comme test supplémentaire, nous examinons ensuite les effets des fusions et acquisitions transfrontalières sur la performance financière des entreprises, dans ce cas, approximés par le bénéfice avant intérêts, impôts, dépréciation et amortissement (BAIIDA) divisé par le total des actifs de celles-ci. Sur la base des coefficients, les fusions et acquisitions transfrontalières ont un effet immédiat négatif et statistiquement significatif sur la performance financière des entreprises. Comme le montrent les colonnes restantes, ces effets négatifs persistent dans le temps, ce qui indique que les fusions et acquisitions transfrontalières ont entraînés une performance financière inférieure et soutenue dans les années qui ont suivi la conclusion de l'opération de fusion et acquisition. Ces résultats sont similaires à ceux trouvés dans (Cozza et al., 2015).

Enfin, bien que nous fassions de notre mieux pour atténuer l'endogénéité potentielle à l'aide des étapes décrites ci-dessous et effectué des vérifications de robustesse avec la méthode différente d'appariement, l'auto-sélection probable de l'engagement dans les fusions et acquisitions transfrontalières

ne peut pas être totalement surmontée. En d'autres termes, les entreprises qui optent pour les fusions-acquisitions transfrontalières pourraient, par exemple, avoir un meilleur accès à l'information sur le marché, bénéficier d'un meilleur accès à l'information, être des entreprises de croissance supérieure en matière d'innovation ou ont un meilleur accès au financement. Ce sont toutes des caractéristiques variables dans le temps qui ne sont pas observées et qui ne peuvent pas être prises en compte. En tenant compte de l'appariement des scores de propension ni de la différence dans les différences. Cela est un problème courant dans la littérature qui cherche à évaluer les effets sur la performance de fusions et acquisitions, qui fait l'objet d'une discussion approfondie (Egger and Hahn, 2010). Les résultats doivent donc être lus et interprétés avec prudence en tenant compte de ces limites.

### **Collaboration internationale pour un rattrapage en matière d'innovation? Le cas des co-inventions chinoises en Europe**

Ce chapitre contribue à la littérature économique concernant l'internationalisation de la Chine et sa tentative de rattrapage technologique. En particulier, j'étudie la relation entre la co-invention internationale et la qualité des brevets déposés par les chinois. Pour cette étude, je m'appuie sur différentes bases de données sur les brevets, notamment PATSTAT de l'Office Européen des brevets et les bases de données Citations, Patent Quality et REGPAT de l'OCDE. Celles-ci contiennent des informations sur l'entreprise qui dépose le brevet, le pays cessionnaire et le pays inventeur, les classes technologiques, ainsi que différents indicateurs de qualité du brevet. Dans mes résultats, je montre que les co-inventions transfrontalières chinoises sont relativement concentrées dans un certain nombre de pays partenaires internationaux et que la part de co-inventeurs internationaux dans les différents domaines technologiques est inférieure à la moyenne internationale. En évaluant la qualité des brevets par le

nombre de citations reçues, le nombre de revendications, les résultats montrent une association forte positive et significative de la participation d'entités chinoises à la co-invention transfrontalière.

En ce qui concerne le développement technologique, du point de vue des chiffres, la Chine a connu une augmentation remarquable et marquée des indicateurs d'intrants et de produits de recherche et développement (R&D) couramment utilisés depuis le début des années 2000. Parallèlement aux taux de croissance élevés de son PIB, de ses dépenses de R&D, de son personnel et de ses infrastructures de recherche, le nombre de ses employés et de ses infrastructures de recherche a augmenté à un rythme impressionnant.

Comme indiqué ci-dessus, un nombre croissant d'entreprises chinoises semble être de plus en plus capables de développer des innovations technologiques. En plus d'entrer sur des marchés étrangers avancés par le biais du commerce et de l'IED, ces entreprises manifestent une volonté croissante de protéger les résultats de leurs efforts de R&D sur ces marchés. Un sujet qui suscite un intérêt grandissant de la part des chercheurs est l'aspect des inventions transfrontalières dans le nombre croissant de dépôts de brevets. En effet, dans le monde entier, la collaboration transfrontalière pour les inventions a augmenté dans tous les domaines technologiques au cours des dernières années, à l'exception des technologies liées à la santé (OECD, 2009, 2017). La collaboration internationale en R&D et les co-inventions transfrontalières ne sont plus seulement réservées aux économies développées, mais touchent aussi de plus en plus les économies émergentes (Branstetter et al., 2015; Giuliani et al., 2016; Chen et al., 2013). Les entreprises des économies émergentes ont de plus en plus accès aux réseaux d'innovation transfrontaliers et y participent progressivement. La co-invention transfrontalière est donc considérée comme un moyen potentiel de transférer les connaissances des économies de pointe vers les économies émergentes. Compte tenu de la taille de son économie et de l'expansion continue de ses activités de R&D aux niveaux national et international, la Chine joue sans doute un rôle de premier plan dans ces

réseaux d'innovation transfrontaliers et des co-inventions transfrontalières des économies émergentes. Toutefois, seul un nombre très limité d'articles ont examiné les tendances des activités de recherche collaborative menées par la Chine à l'étranger et comment la co-invention transfrontalière a participé au rattrapage technologique de la Chine.

Dans ce chapitre, j'examine d'abord le modèle des co-inventions internationales chinoises en Europe en tant que pôle de recherche et développement de premier plan. L'étude se concentre ensuite sur le rôle des co-inventions transfrontalières sur la qualité des dépôts de brevet chinois à l'étranger en les comparant aux inventions créées par des équipes purement nationales. Pour cette étude, je m'appuie sur différentes bases de données sur les brevets, notamment PATSTAT de l'OEB et les bases de données Citations, Patent Quality et REGPAT de l'OCDE. Celles-ci contiennent des informations sur la société candidate, le pays cessionnaire et le pays inventeur, les classes technologiques ainsi que différents indicateurs de qualité du brevet. J'utilise différents indicateurs distincts couramment utilisés dans la littérature économique pour évaluer la qualité d'un brevet, à savoir le nombre de citations antérieures, le nombre de revendications et la taille de la famille de la demande de brevet, c'est à dire le nombre d'offices de brevets l'invention est déposée.

La base de données sur la qualité des brevets de l'OCDE contient des informations sur le champ d'application du brevet, la taille de la famille de brevets, les délais de délivrance et les indicateurs dit "prêts à l'emploi", la généralité, l'originalité et la radicalité du brevet, ainsi que des indices combinant les indicateurs individuels mentionnés. À partir de la base de données des citations de l'OCDE, je fusionne plusieurs variables avec des informations sur le nombre de citations de chaque brevet, à savoir le nombre de citations de brevets effectuées (citations antérieures), le nombre de références à la littérature non-brevets (NPL) et toutes les citations faites en tant que X, toutes les citations reçues, le nombre total de citations reçues dans les 5 ans sous forme de publication européen ou international par l'OMPI.

Mon analyse est relative aux demandes de brevets chinois entre les années 2000 et 2014. L'année de départ 2000 est choisie car il y a moins de 10 co-inventions avant 2000 et le début du nouveau millénaire qui, par ailleurs, marque également le début de l'internationalisation croissante des entreprises chinoises, suivant le concept plus large de la stratégie du gouvernement chinois "Going Out" qui encourage les entreprises à atteindre les marchés étrangers.

J'ai choisi d'estimer l'effet de l'invention transfrontalière sur la qualité des brevets via une estimation de quasi-maximum de vraisemblance de Poisson (Poisson Quasi-Maximum Likelihood: PQML). Le choix de cet estimateur a été fait pour plusieurs raisons. Premièrement, les trois variables de résultat à tester sont des entiers non-négatifs et un modèle de données de comptage doit donc être utilisé. Deuxièmement, PQML permet de prendre en compte la surdispersion présente dans les données. Enfin, mon choix suit la littérature pertinente sur le sujet: les études les plus liées à ce papier ont opté pour une technique d'estimation similaire pour les raisons évoquées.

Dans mes résultats, je montre que les co-inventions transfrontalières chinoises sont relativement concentrées dans un certain nombre de pays partenaires internationaux et que la part de co-inventeurs internationaux dans les différents domaines technologiques est inférieure à la moyenne internationale.

Au niveau mondial, les États-Unis dominant clairement avec un total de 200 co-inventions entre 2000 et 2014 <sup>7</sup>, tandis que tous les États membres de l'UE-28 regroupent un total de 73 co-inventions en comptes fractionnaires. Les autres pays contributeurs importants sont Taiwan (total: 36), le Canada (27), le Japon (10), l'Australie (10) et la Suisse (6).

D'autres pays asiatiques voisins de la Chine, à l'exception de Taïwan, ne jouent qu'un rôle très mineur dans les activités chinoises de la même invention à travers les demandes chinoises déposées à l'OEB: Singapour

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<sup>7</sup>Troncation des données de brevet à partir de 2013

(total: 3), Inde (3), Corée (1) et la Russie (1) montrent tous une faible propension à co-inventer avec les inventeurs chinois pour les dépôts de brevets chinois en Europe.

Au niveau européen, les équipes d'inventeurs en Allemagne constituent le premier groupe de co-inventeurs avec en comptes fractionnaires de 21. Les autres grands pays européens de co-invention sont la France (13), le Royaume-Uni (10), la Suède (10), l'Italie (8). En ce qui concerne les principaux pays partenaires mondiaux en matière de co-invention, ces chiffres sont des indicateurs puissants indiquant où les entreprises chinoises répartissent leurs activités de R&D à l'étranger et avec lesquels la Chine entretient les liens scientifiques et industriels les plus solides.

En termes de distribution, les classes technologiques, telles que définies par l'OMPI, pour lesquelles sont attribuées les demandes de brevet chinois en Europe présentent une forte hétérogénéité dans leur part de co-invention internationale. La catégorie "machines-outils" est en tête de liste et représente 15%. D'autres domaines technologiques tels que la chimie sont également en tête. Par exemple, la chimie fine organique, la biotechnologie, l'industrie pharmaceutique, et l'ingénierie chimique montrent un degré relativement élevé de participation nationale au processus d'invention. Les meilleurs champs en termes de nombre total d'applications dans notre échantillon, tel que la communication digitale, la télécommunication, l'informatique et la machinerie électrique, appareils, et énergie, appartiennent tous au domaine technologique de l'ingénierie, et affichent une part relativement faible de co-invention internationale.

En évaluant la relation entre les co-inventions transfrontalières et la qualité du brevet en utilisant les variables substituts du nombre des citations reçues, de revendications et de la taille de la famille du brevet, les résultats montrent une association forte positive et significative de la participation d'entités chinoises à la co-invention transfrontalière.

# Introduction

China's economic development is arguably one of the most fascinating and important topics in the world economy today. Within 40 years, since the opening up and economic reforms of China in the late 1970s, China has transformed from a closed, economically relatively backward country to the second largest single country economy of the world.

Driven by investment- and export-led growth, China became a very successful low-tech manufacturing economy in the 1990s and early 2000s. Continuous economic reforms and its comparative advantages in labor-intensive works have sustained high growth levels for more than two decades and made China the industries working bank of the world by the start of the millennium. Policies and investments have since then been increasingly made in the attempt to transform the country into a knowledge- and innovation-driven economy. In fact, China not only aims to become a high-tech country with advanced manufacturing of the level of developed countries but also the innovation leader of the world by the middle of the century.

The underlying worry, mounting major constraint and a driving motivation in this endeavour is the potential facing of the "middle income trap" (Woo, 2012; Worldbank, 2013). Economic theory and history suggest that developing countries can get stuck at a certain income level relative to the leading economies of the world. The risk is that the developing country gets caught in such a position, unable to compete on the one side with low-income and low-wage economies for manufactured exports, and on

the other side with advanced economies for highly skilled and lucrative innovations. (Asia Development Bank, 2011).

The most crucial "tool" to overcome the middle income trap and sustain dynamic growth is innovativeness in its various forms (Worldbank, 2015, 2013). For this China has shown massive efforts to build up inventive capacity and to generate a catch-up momentum in innovation. This has been manifesting itself successfully already in a range of industries, such as in information and communication technology and renewable energy, and measured in various innovation indicators. (Fu, 2015; Li and Zhang, 2018).

Indeed, looked at the issue of technological development from a pure numbers perspective, China has shown a remarkable increase of commonly used research and development (R&D) input and output indicators since the early 2000s. Parallel to high growth rates in its GDP, R&D expenditures, science and technology personnel and research infrastructure numbers have risen at an impressive pace. On the R&D output side, patent numbers of Chinese firms have "exploded" (Hu and Jefferson, 2009; Hu, 2010). Patents, as the most well known form of intellectual property rights, are meant to incentivize inventive activity and merit the owner with monetary rewards for it. In fact, China's State Intellectual Patent Office (SIPO) has become the world's largest filing office in 2014. Chinese patent application and grants have also soared in major foreign patent offices, such as the United States Patent and Trademark Office (USTPO) and the European Patent Office (EPO), as well as the World Intellectual Property Organization (WIPO), where patent protection is subject to more rigorous examination. (Kesan et al., 2016; van Dijk et al., 2015; Wunsch-Vincent et al., 2015). In Europe, Chinese telecommunications giant Huawei has become patent application filer number one at the EPO in 2017 and a rising number of other Chinese technological firms such as Xiaomi, BYD and Tencent are increasingly filing their inventions there. Hence, a growing number of Chinese firms seems to be more and more capable of technological inventorship.

Yet, Chinese inventions and patent filings are often perceived as of lower quality vis-à-vis technologically leading countries and only a limited number of Chinese companies are able to compete in mature Western, high-technology markets. Further, the majority of Chinese firms still lacks advanced production technology. As (Fu et al., 2016) explain, the lack of advanced production technology is a key difference between a developing country and a developed country. For the developing country, productivity growth could be achieved by two ways,

- i) the adoption of more advanced existing technology from abroad (through channels such as licensing, international trade, foreign direct investment, skill migration, international research collaboration, disembodied knowledge diffusion, and transfer and spillover of technology through participation in the global value chain) and
- ii) the strengthening of indigenous technological innovations.

This doctoral thesis revolves around the analysis of China's policies, foreign direct investment, and international collaboration with regard to innovation. More specifically, as the title 'Indigenous Invention, M&A, and International Collaboration' implies, it takes three different perspectives on China's rise to innovation:

Chapter one, co-written with Ilja Rudyk explores China's indigenous innovation policies. They are analyzed in regard to their success in yielding more domestic ownership in 'strategic' technologies that the Chinese government considers key for its national and economic trajectory in the future. Chapter two, co-written with Anthony Howell and Jia Lin, explores the role of Chinese cross-border mergers and acquisitions for domestic innovation performance. Finally, chapter three takes a closer look at the role of international collaboration in China's invention quality.

In the following sections, I will briefly introduce the background and contribution of the three following chapters and their content. Subsequently, the structure of the thesis is presented.

## **Chinese innovation policies and the rise of "indigenous" inventions in European patent data**

Developing independent innovative abilities and reducing the dependency on foreign technology lays at the core of the way China's innovation policy plans, regulations and intellectual property laws have been shaped over the last decade. Two cornerstones and directives of this overarching objective are China's National Medium and Long-Term Program for Science and Technology Development and the 12th Five-Year National Development Plan of Strategic Emerging Industries promulgated by the State Council in 2006 and 2012 respectively. As one of their major goals, they aim at developing an increased ownership of Intellectual Property Rights (IPRs) in targeted technology classes that the Chinese government considers key for the future development of its country.

The objective of this chapter is to analyze whether there has been an observable effect of the (indigenous) innovation policies on China's overseas inventions, as measured in Chinese patents as a proxy for Chinese innovation capacities and activities. Further, we are interested in the question if there has been a detrimental effect of the policies on the quality of the inventions filed in the specifically targeted fields. Recent studies have found that the quality of both domestic as international Chinese patent applications has decreased due to Chinese innovation and IPRs policies such as direct subsidizing Patent Cooperation Treaty (PCT) applications.

We use a difference-in-differences approach to test i) whether China increasingly owns its indigenous inventions in the targeted technology fields by looking at developments in Chinese as opposed to foreign "ownership" of patents which involve Chinese inventors and ii) whether there have been observable changes in the quality of these inventions. To this end, we construct a dataset composed of all patent applications which have been invented or co-invented by a Chinese resident at the European Patent Office (EPO) using patent information data from the EPO. Moreover, we create a attribution table for the strategic technologies targeted in the

MLP (SEI respectively) and patent sub-classes at the 4-digit International Patent Classification (IPC4) level, using the World Intellectual Property Organization Categorization Tool, IPCCAT. In order to assess the impact on patent quality, we use different patent quality indicators, provided by the OECD in its Patent Quality database, which is merged to our unique dataset.

Despite certain limitations explained in the chapter, our results suggest that both policy plans contributed to an increased ownership of the targeted technologies. Further, we are interested in the question if there has been a detrimental effect of the policies on the characteristics of the inventions filed in the specifically targeted fields. Here we find differing results for the two plans and depending on the indicator used. While the introduction of the MLP policies is found to have led to less claims but no indication of a significant change for forward citations and family size in the targeted classes. For the SEI, our results point at a positive effect on impact and quality of the targeted classes.

## **Outward Direct Investment and Domestic Innovation**

Outward-going direct investment (ODI) from China has seen a sharp increase since the early 2000s and China's accession to the WTO and the start of its "going global" strategy. The Chinese government is strongly committed to promoting the internationalization of Chinese companies in order to improve access and benefit from resources, markets, know-how, high-tech and economies of scale and scope. With the help and support of the Chinese government, Chinese companies are becoming more internationalized and expanding investments abroad. Indeed, Chinese entities increasingly invest in developed economies in search of strategic assets and rapid technological scale up, predominately via mergers and acquisitions (M&A) (Amighini et al., 2013; Duysters et al., 2009; Huang and Wang, 2013; Di Minin et al., 2012; Peng, 2012; Spigarelli et al., 2013).

However, the net effect of mergers and acquisitions is ambiguous and empirical studies that looked into the effects of mergers and acquisitions on innovation performance have found mixed results. This chapter explores the effects of Chinese firms' outward direct investments (ODI) on the subsequent domestic innovation and financial performance of Chinese listed companies.

As an identification strategy, the study in chapter two employs matching techniques combined with a difference-in-differences estimator to investigate the causal effects of cross-border M&A on firms' investments in innovation, innovation outputs, and financial performance. To this end, we construct a unique firm-level data set, linking the general business and financial information for all companies listed at China's A-share stock exchange markets at Shanghai and Shenzhen (WIND database) with all cross-border, majority M&A deals (leading to a stake of at least 10 percent in the target company) of these firms (Zephyr database, Bureau van Dijk). We also add the domestic patent portfolios of the firms to the dataset, using public patent information of the State Intellectual Property Office of China (SIPO).

We show that engaging in cross-border M&A has a strong and positive association with a rise in post-deal R&D intensity of the firm investing as well as with a rise the patent applications and grants in the years following the investment. We find the same positive relationship for patent quantity as proxied by the number of claims in the patent applications. With regard to post-deal financial performance our results, however, indicate a negative association for the years following the cross-border M&A deal of Chinese listed firms.

## **The Role of International Collaboration in Chinese Inventions**

International collaboration in R&D and cross-border co-inventions are no longer reserved to countries from developed economies alone, but increasingly performed by emerging economies, too. Companies from emerging economies have increasing access to and increasingly engage in cross-border innovation networks. Given the sheer size of its economy and increases in R&D and internationalization efforts and expenditures of its companies, China arguably takes a special and leading role in these cross-border innovation networks. Cross-border co-invention are seen as a potential means to transfer knowledge from technologically leading economies. This chapter first investigates the pattern of Chinese international co-inventions in Europe as a leading R&D hub and then scrutinizes the role cross-border co-invention play for the quality of Chinese overseas patent applications. It thereby contributes to the understanding of China's internationalization and technological catch-up.

For the study in chapter three, I rely on various patent information databases, namely EPO's PATSTAT and OECD's Citations, Patent Quality and REGPAT databases for information on the applicant firm, assignee and inventor countries, technological classes as well as quality indicators of the patent. Given the count data nature of these indicators such as forward citations, number of claims and family size of the patent application, the relationship between cross-border co-invention and patent quality is estimated via poisson quasi maximum likelihood.

In my results, I show that China's international co-inventive activity in patent applications in Europe is concentrated in terms of technologies and partner countries. Econometric results found in the study demonstrate that international co-invention activity of Chinese firms is associated with an increasing patent quality of Chinese patent applications at the EPO. Chinese patent applications which involve international co-inventors during its creation process are found to feature more forward citations, a higher

number of claims and a larger family size of patents as compared to patent applications developed in China only.

The remainder of this doctoral thesis is structured as follows. In chapter one, Ilja Rudyk and I explore China's innovation policies and assess their impact with regard to domestic ownership in strategic technologies in European patent data. Chapter two, which is joint work with Anthony Howell and Jia Lin, provides an empirical analysis of cross-border M&A by listed Chinese firms and their effect on the domestic innovation activities and financial performance. Finally, in chapter three I address the relationship between international collaboration and patent quality through an analysis of Chinese patent applications in Europe.

# 1

## **The Rise of Chinese “Indigenous” Inventions: Evidence from European Patent Data<sup>1</sup>**

After 30 years of unprecedented economic development, thriving to a large extent on the production and export of manufactured goods, China has undertaken massive and wide-reaching efforts to change its engine of growth, ultimately willing to push its economy towards a more services- and innovation-driven economy. Since the early years of the new millennium, domestic, “home-grown” and independent innovation has become a top priority list of its leaders, rhetorically as in terms of resources allocated to the matter. Developing independent innovative abilities as well as reducing the dependency on foreign technology represents the core of the way innovation policy plans, regulations and intellectual property laws have been shaped over the last decade (Ahrens, 2010; Chen and Naughton, 2016; Hout and Ghemawat, 2010; Luginbuehl, 2014; Prud’homme, 2012,

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<sup>1</sup>Co-written with Ilja Rudyk, email: [irudyk@epo.org](mailto:irudyk@epo.org). We would like to thank Theon van Dijk for his advice and valuable input to this work. We are also grateful for comments of participants of Eu-SPRI ECS summer school in Utrecht, GSIE seminar at Paris 1 University, Fudan-IEA workshop in Paris and the PhD seminar at Zhejiang University. We thank Yan Guo, Mao Hao, Anthony Howell, Can Huang and Dan Prudhomme for helpful discussion. A doctoral mobility scholarship of French region Ile de France through its AMI program was highly appreciated.

2013a). For China’s leaders, “holding key technology in [our] own hands” and “independent innovation” are considered most crucial for competition, development and a wide range of economic and national security issues and “the only way” to guide China “to the summit of science and technology.”<sup>2</sup>

Two cornerstones and directives of this overarching objective are China’s National Medium- and Long-Term Program for Science and Technology Development (MLP) promulgated by the State Council in 2006 (The State Council, 2006) and the 12th Five-Year National Development Plan of Strategic Emerging Industries (SEI), issued by the State Council in 2012 (The State Council, 2012). As one of their major goals, they aim at developing an increased ownership of Intellectual Property Rights (IPR) in targeted technology classes that the Chinese government considers key for the future development of its country (Gao, 2015; Hu and Jefferson, 2009; McGregor, 2010; Prud’homme, 2012, 2013a; Serger and Bredne, 2007).

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<sup>2</sup>Quotes taken out of the speech “Transition to innovation-led growth” by President Xi Jinping at the 17th General Assembly of the Members of the Chinese Academy of Sciences and the 12th General Assembly of the Members of the Chinese Academy of Engineering, Beijing, June 2014, in Xi (2014), full quote as follows: “(...) Years of painstaking efforts have resulted in great progress for China in science and technology, and China has entered the advanced ranks in the world in some important fields. In certain fields, it has become a “forerunner” or “parallel runner” instead of a “follower”. China has entered a vital period, when new industrialization, application of information technology, urbanization and agricultural modernization are forging ahead simultaneously, in parallel or interactively. This has created ample space and an unprecedentedly strong momentum for independent innovation. (...) generally speaking, the foundation of our scientific and technological innovation is not solid enough; our independent innovation ability, especially in the area of original creativity, is not strong. We still have to depend on others for core technology in key fields. Only by holding key technology in our own hands can we really take the initiative in competition and development, and ensure our economic security, national security and security in other areas. We cannot always decorate our tomorrows with others’ yesterdays. We cannot always rely on others’ scientific and technological achievements for our own progress. Moreover, we cannot always trail behind others. We have no choice but to innovate independently. Facts prove that it is self-sufficiency that has enabled the Chinese nation to stand among the world’s independent nations, and independent innovation is the only path to the summit of science and technology. With this understanding, we should waste no time in making a difference. We cannot keep on talking year in and year out but do nothing about making a drastic change (...)”

The objective of this study is to analyze whether there has been an observable effect of these (indigenous) innovation policies on China’s overseas inventions, measured in Chinese patents as a proxy for Chinese innovation capacities and activities. Further, we are interested in the question if there has been an observable effect of the policies on the characteristics of the inventions filed in the specifically targeted fields after the implementations of the policy measures. Recent studies have found that the quality of both domestic and international Chinese patent applications has decreased, due to Chinese innovation and IPR policies such as direct subsidizing Patent Cooperation Treaty (PCT) applications (Dang and Motohashi, 2015; Lei et al., 2012; Boeing and Mueller, 2015, 2016).

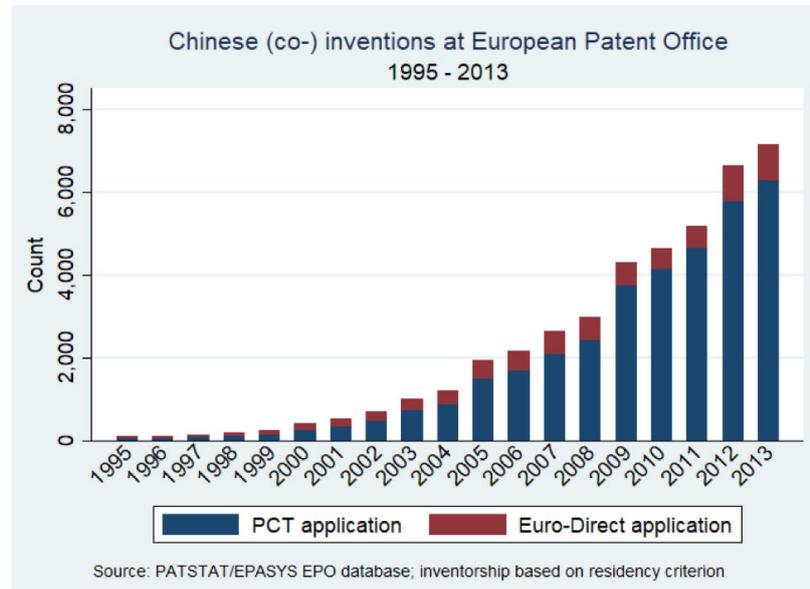
More precisely, we use a difference-in-differences approach to test i) whether China increasingly owns its indigenous inventions in the targeted technology fields abroad by looking at developments in Chinese as opposed to foreign “ownership” of patents which involve Chinese inventors and ii) whether there have been observable changes in the characteristics of these inventions that would reflect a change in the quality. To this end, we construct and rely on a dataset composed of all patent applications which have been invented or co-invented by a Chinese resident at the European Patent Office (EPO) using patent information data from the EPO. Moreover, we create a concordance table between the strategic technologies targeted in the MLP (SEI respectively) and patent subclasses at the 4-digit International Patent Classification (IPC4) level, using the World Intellectual Property Organization Categorization Tool, IPCCAT. In order to assess the impact on patent quality, we use different patent quality indicators, provided by the OECD in its Patent Quality database, which is merged to our unique dataset. In our results we find that the policy plan for Strategic Emerging Industries contributed to an increased ownership of the targeted technologies. With regard a potential change of patent quality due to the policy plans, our results suggest a positive association with the number of backward citations and the family size of the patents. Our study strives to contribute to the literature on innovation policies

in emerging economies and the understanding of China’s technological development and catch-up attempt in particular.

The remainder of the paper is organized as follows: Section two illustrates the inventions and patenting of Chinese companies with the focus on patenting in Europe and at the EPO. Section three then provides an overview of Chinese innovation policies and China’s strategic industries in the MLP and SEI. Section four reviews the existing literature and develops the hypotheses to be tested. Section five presents the data and concordance table developed. Section six presents the methodology and section seven shows and discusses our results. Finally, section eight concludes.

## 1.1 Chinese inventions and their ownership in Europe

Clearly, Chinese domestic and foreign patenting activities have shown an enormous surge since the beginning of the millennium, as several academic articles and studies by several major patent offices, including the European Patent Office (EPO), United States Patent and Trademark Office (USPTO) and World Intellectual Property Office (WIPO) have shown (van Dijk et al., 2015; Eberhardt et al., 2017; Hu and Jefferson, 2009; Kesan et al., 2016; Wunsch-Vincent et al., 2015). These studies are based on Chinese patent *applications*, meaning patent applications which have a Chinese resident registered as their first applicant. Another way to look at inventive and patenting activities of a country is by analyzing its *inventions*, i.e. patents applications which were invented by residents of a country. Here, Chinese activities have experienced a spectacular increase, too. Indeed, Figure 1 below illustrates this “explosion” of Chinese inventive activities registered as IP in Europe via Euro Direct and Euro PCT patent applications with inventors from China at the EPO between 1995 and



**Figure 1.1:** Chinese (co-)inventions at the European Patent Office, 1995-2013

2013<sup>3</sup>. Further, although both types of filings have been increasing, most applicants of Chinese (co-)inventions have used the PCT route, indicating that they seek protection for the invention in other regions of the world, too.

The focus of this paper lays on the (co-)inventions from Chinese entities which can be observed in Figure 1: Patents with at least one Chinese inventor filed at the EPO have increased at a rapid pace. From 120 inventions in 1995, the compound average growth rate (CAGR) between 1995 and 1999 laid at 21 percent to reach 255 (co-) inventions in 1999 and increased with a CAGR of 24 percent between 2000 and 2013 to 7,139 (co-)inventions from Chinese residents in 2013. 88 percent of the latter were PCT applications.

<sup>3</sup>When applying for patent protection in Europe, applicants can choose between i) filing at the respective national IP offices (National route), ii) filing at the EPO for a European (Euro Direct) patent for some or all of the contracting states of the European Patent Convention (EPC) (European route), or iii) filing at the EPO an international patent application with the EPO as receiving office and the optional posterior choice of the application’s entry into the European phase (Euro PCT/ International route). The publication of such an application having entered the regional phase can take up to 30 months. Therefore in our data extracted in the beginning of 2017, only Euro PCT figures from up to 2013 are complete and truncation of our data starts in 2014.

The ownership - defined by the first applicant - of these applications with Chinese (co-)inventions is in the center of our analysis. As Figure 2 below, showing the ownership distribution by countries/country blocks of Chinese (co-)inventions at the EPO between 1995 and 2014<sup>4</sup>, demonstrates, Chinese (co-)inventions have been increasingly owned by Chinese entities (“CN”): While in 1995 around 48% belonged to a Chinese first applicant/owner, this ratio rose to reach 53% in 2000, 62% in 2005, 72% in 2010, 73% in 2013, the last year with complete data in our extraction, and 81 percent recorded for 2014. Simultaneously, the share of the two other traditionally largest owner of (co-) inventions from China, countries from the European Patent Convention country block (“EPC”) and the United States of America (“US”), has been decreasing to 12% (EPC) and 10% (US) in 2013, respectively. Other country blocks are nearly negligible, with Japan (“JP”) owning less than 2%, Korea (“KR”) less than 1% and Other Countries/the Rest of the World (“RoW”) around 3% in 2013.<sup>5</sup>

## **1.2 China’s indigenous innovation policies**

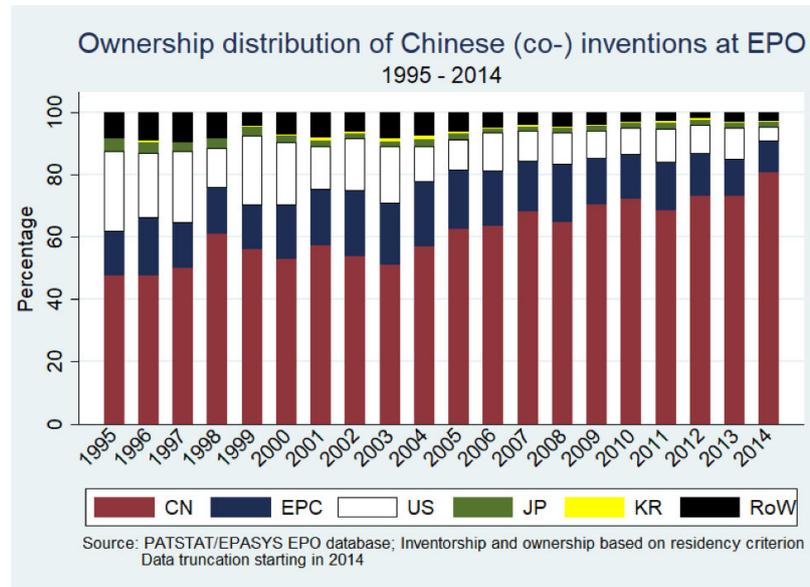
### **1.2.1 China’s innovation policies**

This subsection gives a short overview on the development and major programmes and targets of China’s national innovation policies. While the Chinese concept and definition of indigenous innovation will be explained in section 3.1.2 below, innovation policies can be broadly defined as “a set of policy actions, measures, and tools intended to raise the quantity and

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<sup>4</sup>Data truncation starting in 2014, see footnote 2

<sup>5</sup>It is important to note here that in case of the Chinese (co-)inventions the Chinese owner/first-applicant/resident appear to be a Chinese entity in the sense of a domestic entity instead of belonging for example to subsidiaries of China-based foreign Multinational Enterprises (MNEs). For verification, we took a random sub-sample of 500 Chinese “owners”/first applicants between 2001 and 2014 and manually checked their origin. In only 5 cases the name of the owner/first applicant was found to be of foreign origin, for example Bosch Automotive Products (Suzhou) or the Joint-Venture Degussa (Wellink Silica) (Nanping). Hence; only around 1 percent of such “Chinese owned” inventions appear to belong to foreign entities residing in China.



**Figure 1.2:** Distribution of ownership of Chinese (co-)inventions at the European Patent Office, 1995-2014

efficiency of innovative activities and enhance the innovative capability” (Cowan and van de Paal, 2000, p.9) and ”as a kind of institutional arrangement covering a wide spectrum of R&D related activities, innovation policies play a critical role in remedying market failures, building innovation networks, creating a fertile innovation environment, and improving overall innovation capacity” (Liu et al., 2011, p.918).

Liu et al. (2011) divide modern Chinese innovation policies into different phases where the national S&T conferences in 1978, 1985, 1995, 1999 and 2006 mark their milestones. For the purpose of this study and with regards to the specific indigenous innovation policies, we adopt an adjusted version of this structure by distinguishing two markedly different phases in Chinese innovation policies. The overview in following figure 1.3 illustrates these phases and their respective major S&T programs and IPR legal system advancements and reforms along a timeline<sup>6</sup>. In addition, we add short descriptions of the last four Five-Year-Plans with a focus on the innovation and S&T policy guidelines that these major social and

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Source: Authors’ illustration based on Figure 3.1. (p.45) in OECD (2007) and Figure 1 (p.5) in Frietsch and Wang (2007)

economic development plans stipulate for the respective time periods.

### **Experimental phase, structural reform and deepening of the S&T system (1978-2005)**

Early innovation policies in China’s post-Mao era have been developed since 1978, as a part of Deng Xiaoping’s launched reforms and overall shift from Soviet-style socialist economic planning to a more market-driven system. In the S&T reforms initiated by Deng Xiaoping and continued by Jiang Zemin until the end of the millennium, China acted in a top-down, incremental and trial-and-error approach, with an emphasis on re-building an independent research base after its destruction during the Cultural Revolution, as well as more market- and product-oriented research. With the aim to complement the increasing investments in its manufacturing capabilities, these reforms included five major programs<sup>7</sup>, envisioned to make S&T serving economic growth and social development. The formerly dominating state owned entities - in particular China’s public research institutes - and universities were subject to a higher exposure to market mechanisms or a complete integration or transformation into R&D units of private companies (Campell, 2013; Guan and Yam, 2015; Liu et al., 2011; Liu and Lundin, 2008). How important the former and current public research institutes (PRIs) have been for the own technological development

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<sup>7</sup> Namely:

1. Key Technologies R&D program (1982), aimed at re-built and push of industrial technology,
2. Spark program (1986), aimed at the development of the rural economy through S&T,
3. High-Technology Research and Development (“863 Program”) (1986), focus on basic and applied for marketable technologies,
4. Torch Program (1988), aimed to promote high-tech industrialization and commercialization in new high technology fields,
5. State Basic Research and Development Program (“973 Program”) (1997), support of basic research in “cutting-edge” technologies

For a more detailed presentation and discussion of these programs, see Campell (2013); Liu et al. (2011); Worldbank (2013)

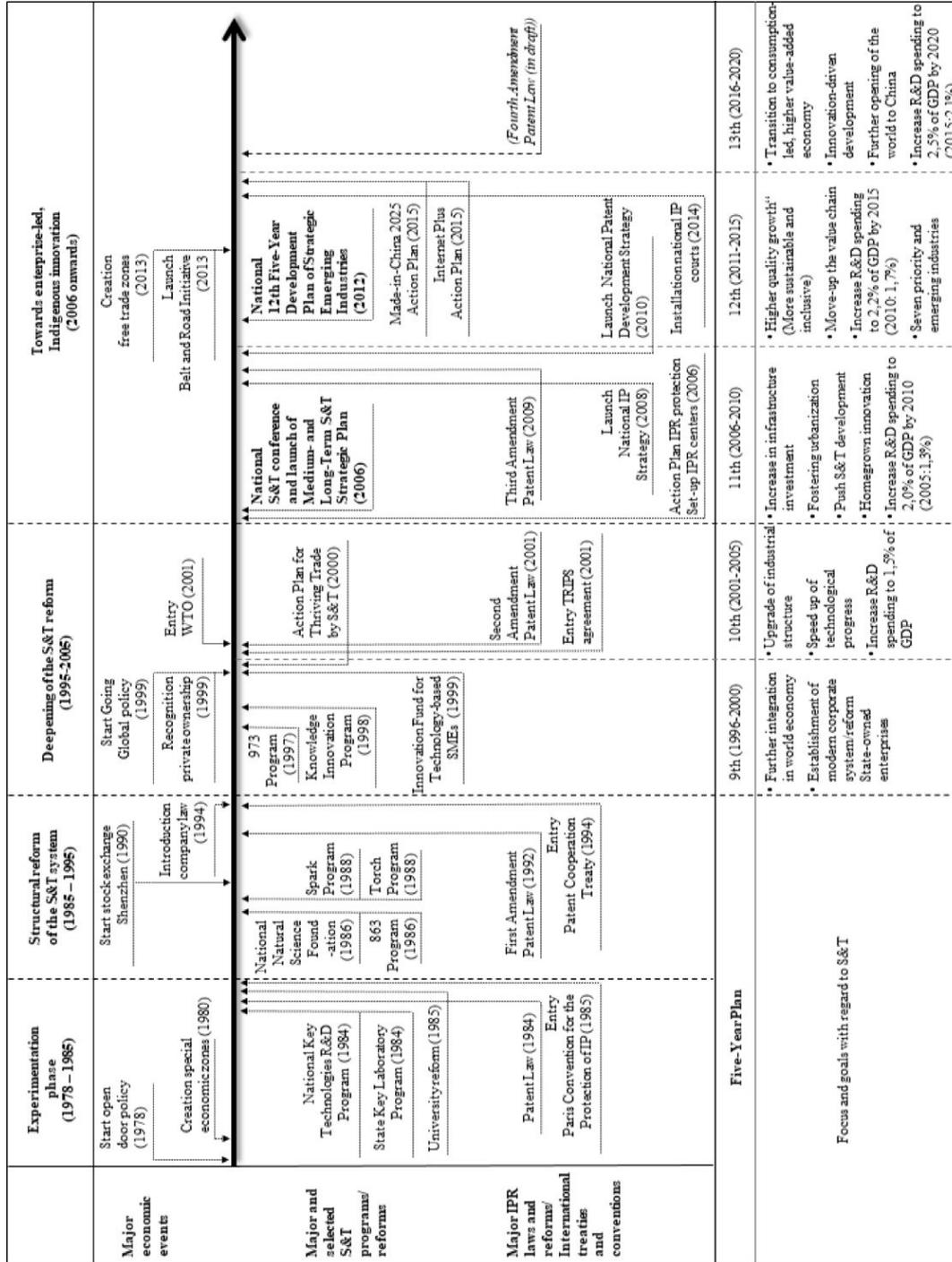


Figure 1.3: Schematic overview of China's innovation policies

of leading Chinese tech companies can be seen by looking at telecommunications giants Huawei and ZTE - both ranking amongst national (at China’s State Intellectual Property Office SIPO) and international (PCT) top patent filers over the last years, and their close collaboration with local research institutions in pursuit of a variety of R&D co-projects (Hu and Mathews, 2008).

An infrastructure for technology transfer and commercialization was built in 2000 through the Action Plan for Thriving Trade through S&T (OECD, 2008). Further, since the end of the 1990s and under the reigns of the Hu and Xi governments, innovation policies have been directed towards high-technology industrialization and increased state support for private companies and their increasing innovation efforts, including and especially for small and medium sized enterprises (Hu and Mathews, 2008; Li, 2009; Liu and Lundin, 2008). Another major program targeted the Chinese Academy of Sciences (CAS), located at the Chinese intersection of government, public and private research and industrial application.

### **Towards enterprise-led, indigenous innovation (2006 onwards)**

The National Science and Technology Conference in January 2006 is widely recognized as a major and decisive shift in terms of the magnitude of resource allocation and top priority setting of innovation policies by the Chinese leadership. At this event the ”Medium- and Long-Term Strategic Plan for Development of Science and Technology (2006-2020)” (MLP) was issued by the Chinese Communist Party Central Committee and the State Council (The State Council, 2006).

The MLP stipulated and quantified the following major goals in order to account for its overarching ambition to transform China into an ”innovation-oriented society” by 2020: i) increase of R&D spending to around 2.5% of GDP by 2020 (up from 1.3% in 2005) ii) increase of contributions to economic growth from technological advance to more than 60% iii) Re-

duction of the dependence on imported technology to no more than 30% and a push of domestically developed instead (Sergey and Breidne, 2007). A particular focus has been put on the development and promotion of so-called “indigenous innovation” as a core concept of economic development and with major impact on the Chinese development initiatives: The MLP here defined indigenous innovation as innovation reached through either original innovation (原始创新, *yuanshi chuangxin*), integrated innovation (集成创新, *jicheng chuangxin*) or assimilated innovation (引进消化吸收再创新, *yinjin xiaohua xishou zai chuangxin*) (Prud’homme, 2013a). Further, in an accompanying document issued by the Ministry of Science and Technology (MOST), the National Development and Reform Commission (NDRC) and the Ministry of Finance at the end of 2006, “The Guideline for Recognizing Indigenous Innovative Products” defined indigenous innovation products as: i) products mainly developed by domestic companies, ii) products with domestic ownership of their intellectual property rights, including patents and brands, iii) products with a technological advance compared to existing products (OECD, 2008, p.576).

Parallel and complementary to the developments and measurements presented above, the Chinese government has promulgated and implemented several patent law reforms and gradually strengthened the protection and enforcement of IPR. The country’s IP system was initialized with the first patent law and the establishment of the State Intellectual Property Office (SIPO) in 1984. The law was revised three times since then, notably in 1992, 2001, and 2009 and a fourth amendment is in draft, with each amendment serving different goals and external requirements. In principle, amendments in 1992 and 2001 aimed at the attraction of foreign investment and the desired and needed technology transfer. They were partly required by international treaties through China’s entry into the WTO and the joining of the TRIPS agreement. With the in theory then established advanced IPR protection framework in place, the 2009 amendment mainly aimed at serving China’s national interests, including a push of technology transfer, patent quality and indigenous innovation capacity (Ganea, 2010). In this context, the latter has been identified crucial to

enable Chinese companies to “(...) create and protect their own IP rights and free themselves from what was often considered the dominance of IP rights owned by foreign companies, who could set the conditions for the manufacture of their protected products and request licensing fees which left Chinese producers with little profit.” (Luginbuehl, 2014, p.4)

The 2009 revision of China’s patent law was part of and complement to the MLP described above and in particular China’s National Intellectual Property Strategy (NIPS) for the period from 2008 to 2020 and the National Patent Development Strategy (NPDS) for the period from 2011-2020. Next to the revision and improvement of the patent law and the general enforcement of patent rights, both strategies specifically stress and serve the creation of domestic innovation (Luginbuehl, 2014). The NIPS broadly states as its strategic goal that by 2020, “(...) China will become a country with a comparatively high level in terms of creation, utilization, protection and administration of IPRs (...)” (The State Council, 2008, p.4). Further, it stipulates that by 2015, “(...)The level of the self-relied intellectual property will be higher by a large margin and the quantity of intellectual property will be greater. China will rank among the advanced countries of the world in terms of the annual number of patents for inventions granted to the domestic applicants, while the number of overseas patent applications filed by Chinese applicants should greatly increase.(...)” (The State Council, 2008, p.4).

Specifying and quantifying the National Intellectual Property Strategy in the fields of patents, the National Patent Development Strategy postulates patent policy measures over the period of ten years (2011-2020). Within this time frame, the National Patent Development Strategy emphasizes the rise of patent utilization and industrialization, the proportion of patent-intensive products and the proportion of exported products with IPRs. Further, additional support via laws, regulations, public procurement,

preferential policies like taxation<sup>8</sup>, and patent subsidy policy<sup>9</sup> should be directed towards the establishment of “core patents” for emerging industries of national interest, in which key technology should be owned by Chinese until the end of the decade in order to enhance China’s competitiveness and independence (The State Council, 2010b).<sup>10</sup>

The National Patent Development Strategy is part and fell into the bigger framework of the 12th 5-Year Plan plan (2011-2015) (Central People’s Government China, 2011)<sup>11</sup> and stipulated to further transform the Chinese economy from the traditional export-oriented, low-value manufacturing at its core to a more domestic consumption-driven economy with a strong innovations and services base. Continuing with the S&T orientation of the former plan, it emphasizes the promotion of the restructuring of key industries by a strengthening of R&D and independent development towards the higher end of the industry chain.

As laid out in the State Council Decision on SEIs (The State Council, 2010a) and the 12th Five-Year National Development Plan of Strategic Emerging Industries (The State Council, 2012)<sup>12</sup> in 2012, seven “strategic emerging” industries were introduced, enjoying massive state-support and preferential tax, procurement and fiscal policies. The support of these industries aligns with the two major themes of the plan, notably

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<sup>8</sup>For an overview of China’s R&D tax incentives in this period, see KPMG (2012). The incentives included reduced corporate tax rates (15 vs 25 percent) for “high and new technology enterprises” (HNTE), a 150% vs. 100% deduction of eligible R&D expenditures, tax concessions for advanced technology service enterprises, customs duty and VAT exemption/refund for R&D equipment purchases and concessions for technology transfers. Additional municipal and local subsidies may have been available depending on the location of the investment.

<sup>9</sup>For an extensive description and critique on the wide spectrum of China’s regulatory and institutional indigenous innovation policies, see McGregor (2010); Prud’homme (2012, 2013a)

<sup>10</sup>English translation of the NPDS available at: <http://graphics8.nytimes.com/packages/pdf/business/SIPONatPatentDevStrategy.pdf>

<sup>11</sup>English translation of the 12th Five-Year-Plan available at: <http://www.britishchamber.cn/content/chinas-twelfth-five-year-plan-2011-2015-full-english-version>

<sup>12</sup>For text of official documents see State Council Decision on SEIs (The State Council, 2010a) and the 12th Five-Year National Development Plan of Strategic Emerging Industries (The State Council, 2012)

sustainable growth and the move-up in the value chain, with the goal to increase the value added to GDP of these industries from 3% in 2010 to 8% in 2015 and to 15% by 2020.

The direction of the 12th 5-Year Plan (2011-2015), described above, and aligning SEI policies was continued and intensified in the guidelines and recommendations of the 13th 5-Year Plan (2016-2020) and its major initiatives for specific industries, such as Made-in-China 2025 and Internet Plus (Aglietta and Bai, 2016; Cheung et al., 2016; Koleski, 2017; Wübbecke et al., 2016).

### **1.2.2 China’s strategic technology fields**

This sub-section provides a listing and short description of China’s strategic technology fields in MLP (2006) and SEI (2012) which are central to this study and which will be used in the concordance table to patent classes and the subsequent econometric analysis below. These industries have been considered as the backbone of the Chinese economy in the future, including the creation of internationally competitive and leading Chinese enterprises, which are consequently in the focus of the indigenous innovation efforts (Cheung et al., 2016; Prud’homme, 2012, 2013a; Raiteri and de Rassenfosse, 2016; Serger and Breidne, 2007).

#### **Strategic technologies in the medium- and long-term plan for scientific and technological development**

The eight strategic technologies in the MLP (The State Council, 2006), as described in section 2.1., are: Biotechnology, Information Technology, Advanced Materials Technology, Advanced Manufacturing Technology, Advanced Energy Technology, Marine Technology, Laser Technology and Aerospace. Table A.2 in the Appendix lists the strategic technology fields and their specific subfields in the MLP.

## Strategic emerging industries

The seven strategic emerging industries in the State Council Decision on SEIs (The State Council, 2010a) and the 12th Five-Year National Development Plan of Strategic Emerging Industries (The State Council, 2012), as described in section 2.1., are: Energy Conservation and Environmental Protection, New Energy, Clean Energy Automobiles, Biotechnology, New Materials, New-generation IT, High-end Manufacturing. Table A.2 in the Appendix lists these strategic technology fields and their specific subfields in the SEI.

## 1.3 Literature Review and Hypotheses

This section discusses the strands of literature that our research touches upon and reviews the findings therein. At the same time, it will expose the contribution our research aims to make and develop the hypotheses to be tested in the ensuing sections.

### 1.3.1 Chinese patenting and its drivers

The development and drivers of *domestic patenting* have been studied extensively in the literature.<sup>13</sup> The drivers identified in the studies on the earlier and later stages of the increase of domestic patenting are ambivalent. On the one hand, they include policy-driven causes, with financial

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<sup>13</sup>Domestic applications for patent protection at the State Intellectual Property Office (SIPO) started with the introduction of China’s patent law in 1984 and first patents were granted in 1986. Generally oriented in its system to the patent systems in use in Germany and Japan, applicants could apply for three types of IP protection considered as a “patent” at SIPO: invention patents, utility models and design patents. In terms of growth dynamics of domestic applications for invention patents at SIPO, one can distinguish between three different periods. Between 1986 and 1993 applications grew relatively moderate. After China’s Patent Law was firstly amended, applications accelerated between 1993 and 1999 to an average growth rate of around 12 percent. It was not until 2000 that domestic invention patents applications “exploded” with an average growth rate of 25 percent between 2000 and 2012.

incentives, government subsidies and Pro-IP legislation as main drivers for filing for domestic patent protection (Hu and Jefferson, 2009; Lei et al., 2012; Li, 2012; Motohashi, 2008). On the other hand, some of the named and other studies found inward-oriented foreign direct investment, an increase of internal R&D expenditures and a rise of technological and innovative capacity to be the main reasons behind the rise (Hu and Jefferson, 2009; Sun and Du, 2010; Zhang, 2010).<sup>14</sup> Further, studies investigating this surge confirmed that it stems mainly from Chinese firms and showed that the share foreign residents and its growth became minor to the domestic since 2003 (Frietsch and Wang, 2007; Hu and Jefferson, 2009). Moreover, the formerly dominating Chinese public research institutions decreased in patenting volumes, while both firms’ and universities’ increased (Motohashi, 2008).

At the same time, only few studies have analyzed the *patenting abroad* by Chinese entities and international entities located in China. Wunsch-Vincent et al. (2015) studied Chinese foreign patenting and in particular foreign-oriented patent families and build a database of foreign-oriented patent families by Chinese residents, i.e. patent applications which have at least one filing office different from the applicant’s origin. The dataset combined data from European Patent Office’s PATSTAT and WIPO’s Statistics Database and comprises both, patent families associated with patent applications as well as with utility model applications. For their descriptive analysis the authors used the foreign-oriented patent family datasets until 2009 and found that only a fraction of the pool of inventive patents and utility models filed domestically gets filed abroad. Further they showed that of those foreign filings around 70 percent target only one foreign Intellectual Property office, a percentage in stark contrast to other top patenting countries US, Japan, South Korea and Germany, where two foreign offices is the most common case. Further, it was shown that Chinese patent families are concentrated in terms of the distribution of technology fields and firms, with more than 50 percent belonging to the “Electrical

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<sup>14</sup>For a detailed overview of the economic literature on Chinese’ domestic and foreign patenting, see Wunsch-Vincent et al. (2015)

Engineering” technology area.

The concentration of applications in this sector in Chinese overseas patenting was confirmed by a study focusing applications at the USPTO: Kesan et al. (2016) in their descriptive empirical work show that China’s patent “boom” is driven by applications in the technology areas of Computers and Communications as well as Semiconductors, Electrical and Optical Systems and Components. Further, the authors compare China’s developments with Japan, South Korea and BRICS states, illustrate that allowance rates at the USPTO converge with the ones of Japanese and South Korean applications and interpret it as an increase in quality of inventions from China. van Dijk et al. (2015) looked at patent applications which involve either Chinese applicants or Chinese inventors at the European Patent Office. The authors report an immense increase in both categories and how Chinese R&D teams are responsible for a rising number of European-owned patents.

Surprisingly, there are very few academic studies which investigate Chinese patenting abroad and the drivers thereof. Eberhardt et al. (2017) constructed a firm-level data set on patent applications at the USPTO and SIPO by Chinese residents between 1985 and 2006 in order to explain the Chinese patent “explosion”. They found that the majority of foreign patenting by Chinese firms for this period is mainly performed only by a few companies, which are concentrated in a few industries, notably the Information Technology sector. Further, patenting was found to be positively associated with export intensity and firms were found to be responsive to patent subsidies by state incentives.

### **1.3.2 Indigenous innovation policies and impact on patent ownership**

As shown in the introduction and sub-section 3.1.2. as well as sub-section 3.2., there has been a resurgence and shift in China’s industrial policy with an increasing focus of Chinese innovation policies on the development

of domestic and independent innovation capacity (Heilmann and Shih, 2013; Chen and Naughton, 2016). China’s ”self-sufficiency” in science and technology and a restriction of reliance on foreign technology by 2020 is to be achieved by ”indigenous innovation” (自主创新, *zizhu chuangxin*) (Cheng and Huang, 2016; Luginbuehl, 2014). *Zizhu*, literally meaning self-directing, stresses autonomy and strategic control of China’s innovation and signaled an increased involvement of the government in the innovation processes since its first formulation in the MLP, too (Lazonick et al., 2016).

The overarching directives and cornerstones of the indigenous innovation policies are the MLP and SEI. They share the main goal to develop and increase ownership of IPR in targeted technology classes that the Chinese government considers key for the future development of its country (Gao, 2015; Hu and Jefferson, 2009; McGregor, 2010; Prud’homme, 2012, 2013a; Serger and Breidne, 2007; Cheung et al., 2016). In this regard, the mentioned policies and their related industry-specific guidelines and directives include a combination and interaction of instruments such as public procurement and related indigenous products catalogues, patent funds, patent subsidies, domestic technology standards, direct R&D support and preferential tax policies with the goal of a strong base of domestically-owned IP in the strategic industries (McGregor, 2010; Prud’homme, 2012; Cheung et al., 2016; USITC, 2011, 2010; USCBC, 2013).

They have been promulgated and implemented at the central and the sub-national, i.e. provincial and municipal level.<sup>15</sup> However, all of these

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<sup>15</sup>For extensive reviews and detailed list of related governmental, provincial and municipal documents, laws, specific articles, circulars, measures and notices, see, for MLP: (Prud’homme, 2012, pp.62-123), (USITC, 2010, pp.95-117), (Cheung et al., 2016, pp.29-37) and for SEI: USCBC (2013), (Cheung et al., 2016, pp.29-37), (Prud’homme, 2012, pp.62-123) and (Prud’homme, 2012, pp.161-225)

Especially the public procurement measures (made in reference to some of the best practices in selected sectors of the US, Japan and Korea) favoring accredited national indigenous intellectual property rights led to sharp protests from foreign firms and governments on the grounds of discrimination and the requirements of the Government Procurement Agreement (GPA) by the World Trade Organization. As a result, respective laws were officially eliminated or changed in favor of equal treatment of domestic and foreign firms (Zhou and Liu, 2016, pp.50-51). However, as recent reports by the US-China

analyses are limited to qualitative and descriptive analysis and do not specifically gauge an effect of the policies on intellectual property and patents nor the ownership of them. To the best of our knowledge, there is no study that tries to empirically measure the impact and effectiveness of the policies on this central aspect of them, Chinese *ownership* of IP in China’s strategic industries.

Drawing on the review of Chinese indigenous innovation policies and based on the theoretical thoughts and anecdotal findings in the economic literature reviewed, the following hypothesis is proposed:

**Hypothesis 1:** *The propensity of Chinese ownership of Chinese indigenous inventions increases in the technology fields targeted in the MLP, SEI respectively, following its implementation.*

### **1.3.3 Indigenous innovation policies and impact on patent quality**

Inventions that are patented differ greatly in quality (Griliches, 1990; Squicciarini et al., 2013b). A limited number of studies has assessed the quality of Chinese patent applications, both domestically<sup>16</sup> as abroad, using different approaches for the concept of quality and value of a patent.<sup>17</sup>

A major drawback concerning Chinese domestic patent data is that it partly does not include adequate information about citations and often

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Business Council USCBC (2015) and US International Trade Commission Cheung et al. (2016) claim, the implementation of these pledges were only partially or not fulfilled at the provincial and local level. Moreover, the reports found new and an increasing number of local regulations linking government procurement with indigenous innovation products and ownership of IP (USCBC, 2015, p.1)

<sup>16</sup>As explained in footnote 11, there are three different types of “patents” which can be applied for and can get granted protection at SIPO, invention patents, utility models and design patents. As utility models and design patents at SIPO do not require substantial examination, “(. . .),it is difficult to determine whether they have novelty and value.” (Dang and Motohashi, 2015, p.5)

<sup>17</sup>For an detailed overview of what patent quality indicators are and how they can be used to account for the quality of patents, see Squicciarini et al. (2013b)

lack well documented information about the claims of the patent (Dang and Motohashi, 2015; Prud’homme, 2013b). Claims and citations, both forward and backward citations, are commonly used in the economic literature as the main and most robust patent quality indicator Squicciarini et al. (2013b).

Dang and Motohashi (2015) analyze domestic invention patent applications at SIPO between 1998 and 2008, testing the impact of different patent policies on patenting behavior. They find that the number of patents is correlated with R&D input and financial output. Moreover, the authors show a 30 percent increase of patent counts driven by the introduction of grant-based patent subsidy policy, but a simultaneous deterioration of patent quality in terms of narrower claims.

Work by Lei et al. (2012) indicates a negative impact of patent subsidies and quota on the quality of domestic patent filings. With the example of a number of cities in China’s Jiangsu province at their patent promoting policies, the authors show that Chinese inventors responded with the production of more patent applications, however with a lower level of quality, as measured in patent claims. In order to benefit from the subsidies and fulfill specific patent application target numbers, claims of applications were split onto more applications leading to an artificial boost and lower quality of domestic patent numbers. Long and Wang (2016) study the impact of patent promotion policies at the provincial level and investigate effects on patent quality proxied by approval, withdrawal and renewal rates of domestic patent applications. Their findings confirm that the introduction of such policies, in particular general subsidies and tax reductions have led to a surge in patent quantity but had a detrimental effect on its quality.

Concerning the international dimension of Chinese patenting activities and its quality, Thoma (2013) investigates various quality indicators in Chinese international patent families as in EPO and PCT applications. The author compares Chinese and foreign applications by different quality indicators

such as the number of grants, the number of oppositions, additional search reports and renewal decisions at the EPO. His findings suggest an, in general, inferior quality of Chinese “indigenous” patents, i.e. by domestic applicants, vis-à-vis those of international applicants. There are very few articles which assess in regard to the impact of China’s patent policies on overseas patenting of Chinese entities. Boeing and Mueller (2016, 2015) build the exception with their analysis of China’s international PCT applications and their quality. The authors build a novel index which is based on citations generated by the International Search Reports of PCT applications and show that the introduction of PCT patent subsidies in China led to a decrease of quality as measured in International Search Reports.

Drawing on the review of patent quality with a particular focus on China and based on the theoretical thoughts and empirical findings in the economic literature previously described, the following second hypothesis is proposed:

**Hypothesis 2:** *The characteristics of Chinese inventions at the EPO has changed in the technology fields targeted in the SEI, after its implementation, reflecting a lower quality.*

## **1.4 Data and concordance table**

### **1.4.1 Data**

We use patent information data from EPASYS, the administrative and monitoring database of the EPO. The original dataset we construct is composed of all published patent applications with a Chinese resident as sole inventor or co-inventor received by the EPO as either Euro-Direct application or Euro-PCT application (having entered the regional phase)<sup>18</sup>

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<sup>18</sup>See footnote 4 for explanation of the different patents and entry paths at the EPO

between 1978 and August 2016. In our definition of Chinese resident for this study we include entities applying for patent protection at the EPO with residence in mainland China, Hong Kong and Macao.

The sample includes the application number, priority date and filing date of the application, the identities and addresses of the inventor(s) and applicant(s) of the application, whether the application is a Euro-Direct application or Euro-PCT application, whether the application was granted patent protection, the respective International Patent Classification (IPC) class-code, the number of claims and the number of the family size of the patent application. Further, it includes information about the number of inventors and applicants and the IPC4 class code. The latter can be used to attribute the application into the primary WIPO technology sector and technology field(s) the application belongs to.<sup>19 20</sup>

We extend our dataset by including information and indicators about patent quality from two different data bases, namely i) the OECD Citations Database (OECD (2018a)) and ii) the OECD Patent Quality Database (OECD (2018b)). The OECD Citations Database includes various information on the citations of a patent applications, e.g. the (forward) citations

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<sup>19</sup>WIPO distinguishes between five broad technology sectors/classes:

(1) Electrical engineering, (2) Instruments, (3) Mechanical Engineering, (4) Chemistry, and (5) Other fields.

These five sectors are further broken down into 35 technology fields:

(1) - Electrical machinery, apparatus, energy; Audio-visual technology; Telecommunications; Digital communication; Basic communication processes; Computer technology; IT methods for management; Semiconductors ;

(2) - Optics ; Measurement; Analysis of biological materials; Control; Medical technology;

(3) - Organic fine chemistry; Biotechnology; Pharmaceuticals ; Macromolecular chemistry, polymers; Food chemistry; Basic materials chemistry; Materials; Metallurgy; Surface technology, coating; Micro-structural and nano-technology; Chemical engineering; Environmental technology;

(4) - Handling; Machine tools; Engines, pumps, turbines; Textile and paper machines; Other special machines; Thermal processes and apparatus; Mechanical elements; Transport;

(5) - Furniture, games; Other consumer goods; Civil engineering

<sup>20</sup>In case of several class codes, we use the first one and follow the technology sector and field structure of the World Intellectual Property Organization (WIPO), which distinguishes five technology sectors and 35 technology fields. For a detailed description of methodology of these sectors and fields see Schmoch (2008) and the complete list in footnote 17.

received, the (backward) citations cited, the number of references to non-patent literature (NPL), or all total citations received as either EP or WO publication.<sup>21</sup>

The OECD Patent Quality Database provides information on the value and characteristics of the patent, such as patent scope (number of technology classes covered), patent family size, grant lag and indices on generality, originality, and radicalness of the patent as well as indices with different compositions of the above. When merging we find that for 7,740 Chinese patent applications in our originally extracted sample from the EPO there is no corresponding information in the OECD datasets. This can be explained by their recent publication date (all missing patent applications in the OECD set were only published in 2016 at the EPO) and were not yet integrated in the two OECD datasets. Because of the very low number of Chinese applications until the year 2000 and for the purpose of the ensuing analysis, we restrict our sample to all applications after 2000. After additional inspection and cleaning of the data from application duplicates, we get our final sample, consisting of 44,021 Chinese patent applications with a Chinese inventor or (co-)inventors at the EPO by 9,221 unique applicants as either Euro-Direct or Euro-PCT patent application between 2000 and 2015.

### **1.4.2 Concordance table**

In order to link the specific technology fields listed in the MLP and SEI to specific International Patent Classification 4-digit patent level classes, we construct a concordance table for both plans. While there is an English translation of the MLP available<sup>22</sup>, we first review the text in the SEI original policy document in Chinese language and translate it to English

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<sup>21</sup>For further information on the OECD Citations database, see <http://www.oecd.org/sti/inno/oecdpatentdatabases.htm>, Oecd (2016) and Webb et al. (2005)

<sup>22</sup>English translation of the MLP available at: [http://sydney.edu.au/global-health/international-networks/National\\_Outline\\_for\\_Medium\\_and\\_Long\\_Term\\_ST\\_Development1.doc](http://sydney.edu.au/global-health/international-networks/National_Outline_for_Medium_and_Long_Term_ST_Development1.doc)

via computer translation. We take the English text of the specific subfield of the respective policy plan, listed in Table A.5 and Table A.6 in the Appendix, and identify its key words of the full text. These keywords are then fed into a categorization assistance tool of the World Intellectual Property Organization (WIPO), IPCCAT<sup>23</sup>, which allows for a classification of the submitted technical key words to patents at the patent main group, IPC class and subclass levels. We choose to attribute three predictions at the IPC4 level per subfield. The IPC4 level is the level commonly used in the economic literature reviewed and most plausible for our purpose. The methodology follows Raiteri and de Rassenfosse (2016), which link 27 so-called frontier technologies in the MLP to IPC4 classes. Initially, we created concordance tables in the way described above for MLP, SEI as well as the 11<sup>th</sup> Five Year Plan for S&T development and the 12<sup>th</sup> National Five Year Plan. While the 11<sup>th</sup> Five Year Plan for S&T development and the 12<sup>th</sup> National Five Year Plan provide lists of targeted technologies, they are rather general overviews and it is only MLP and SEI which provide a detailed description of the targeted technology fields and very specific technologies targeted. They therefore allow for a coherent and detailed classification via the WIPO IPCCAT categorization tool.

## **1.5 Methodology**

### **1.5.1 Econometric specification**

In order to test hypothesis 1 on the rise of Chinese ownership of indigenous inventions, we estimate the impact of both policy plans separately with the difference-in-differences (DiD) estimation as a commonly used identification strategy for the estimation the effect of a specific intervention or treatment with non-experimental data Blundell and Costa (2000). We are interested in the policy impact on the share of Chinese ownership. For this purpose, we estimate the impact of the policies on the likelihood that a

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<sup>23</sup>See WIPO IPCCAT Categorization Assistant at <https://www3.wipo.int/ipccat/>

Chinese invention is owned/filed by a Chinese entity as opposed of being owned/filed by an applicant/owner from another country, distinguishing between two times periods, i.e. before and after the respective policy plan. Our binary response model takes the following form:

$$\begin{aligned}
 P(\text{CN ownership} = 1|X)_{i,t} = & \beta_0 + \beta_1 \text{PlanPeriod}_t + \beta_2 \text{StrategicIPC}_i \\
 & + \beta_3 (\text{PlanPeriod} \times \text{StrategicIPC})_{i,t} + \beta_4 X_{i,t} \\
 & + \beta_5 \text{TechFieldFE}_i + \varepsilon_{i,t}
 \end{aligned}$$

The dependent variable here is the probability that an application  $i$  in year  $t$  is owned by a Chinese entity. Table 1.1 below defines and explains the variables used. Our main variable of interest is the coefficient of the interaction term  $\text{PlanPeriod} \times \text{StrategicIPC}$ , reflecting the impact of the treatment of the targeted technology groups in the respective plan period during the respective time period, with  $\beta_3$  being the DiD estimator. Vector  $X_{i,t}$  includes a number of controls. With  $\text{Europct}_{i,t}$  we control for the simultaneous effects of the filing route (PCT-route vs. Euro-direct route).  $\text{cn\_invent\_only}_{i,t}$  controls if the invention was invented by Chinese inventors only. As the policy measures targeted domestic firms and might not have the same reach on inventions that include inventors residing, we expect this variable to be positive and significant.  $\text{IPC4\_C4}_{i,t}$  indexes competition within the patent’s respective IPC4 class, developed by (Gambardella et al., 2007). It represents the share of the patents held by the top four applicants in each 4-digit IPC patent class in a five year window. and ranges from 0 to 1. Higher value on the index indicates lower competition. Further, we include fixed effects for technology classes on the 35 WIPO technology fields level.

Given the binary outcome variable, we choose in our analysis to use a logistic model (logit) model. An additional linear probability model (LPM) is chosen for comparison. In the logit model, the coefficient cannot be interpreted and one needs to look at the average marginal effects (AME) (Norton et al., 2004; Puhani, 2012). LPM allows for an estimation via

Variable name	Definition and note
<b>cn_owner</b>	Dummy, takes value 1 if the patent application is owned by a Chinese resident, otherwise 0.
<b>PlanPeriod</b>	Dummy, takes value 1 if the patent application has its priority year in the respective treatment time of the respective policy plan, otherwise 0.
<b>StrategicIPC</b>	Dummy, takes value 1 if the IPC4 of the patent application is a targeted IPC4 class of the respective policy plan, otherwise 0.
<b>PlanPeriodxStrategicIPC</b>	Interaction term of PlanPeriod and StrategicIPC, takes value 1 if patent application is in priority year of respective plan period and the IPC4 of the patent application is a targeted IPC4 class of the respective policy plan, otherwise 0.
<b>Controls</b>	
<b>Europct</b>	Dummy, takes value 1 if the patent application is filed at EPO via the PCT-route, otherwise 0.
<b>cn_invent_only</b>	Dummy, takes value 1 if the patent application is invented by Chinese residents only, otherwise 0.
<b>IPC4_C4</b>	An index measuring competition within the patent’s respective IPC4 class, developed by Gambardella et al. (2007). Share of the patents held by the top four applicants in each 4-digit IPC patent class. The index ranges from 0 to 1. Higher value on the index indicates lower competition.
<b>35 WIPO technology fields – FE</b>	Fixed effects for 35 technology fields as defined by WIPO

Table 1.1: Definition of variables

least squares where the DiD coefficient is readily interpretable contrarily to the non-linear model (Ai and Norton, 2003).

Before running regressions, we perform different checks. DiD builds on

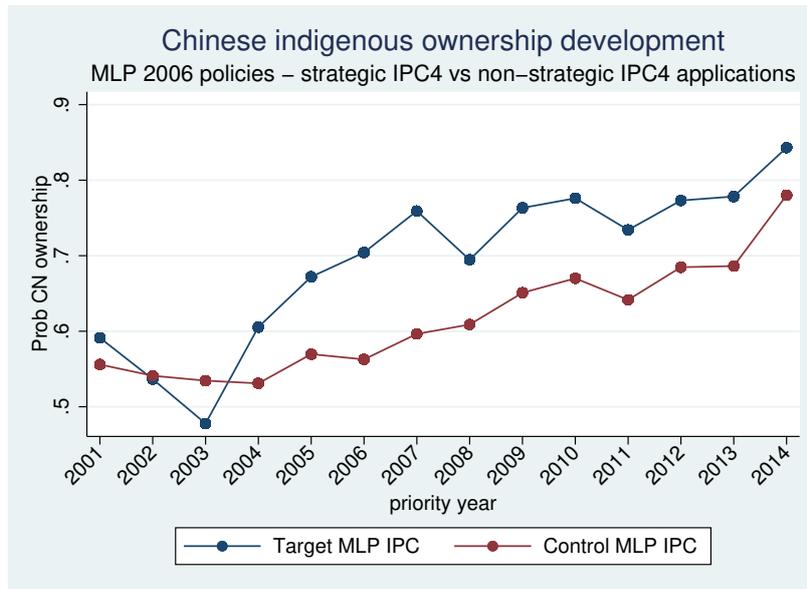


Figure 1.4: Chinese indigenous ownership development (MLP)

different assumptions, with the most critical being the parallel trend assumption. Figure 1.4 and Figure 1.5 inspect this assumption of similar pre-trends of Chinese ownership in treatment and control groups graphically. As it can be observed in Figure 1.4, there were different trends in the share of ownership for the IPC classes in the MLP before 2006, meaning that the parallel trend assumption is violated and is likely lead to a biased estimation of the causal effect.

As for figure 1.4, the treatment and control groups of the IPC classes in the SEI follow a similar trend until 2012, as shown in Figure 1.5. For the analysis of the treatment effect of the SEI in 2012, we consider the period from 2006 until 2014. 2006 marked the start of the MLP and the relative increase in 2006 of targeted vis-à-vis control group IPCs of the SEI policy is likely to be influenced from the part of the SEI targeted technology classes which were targeted in 2006 by the MLP already. In our following regressions we will account for this by controlling for the overlapping classes in the SEI analysis.

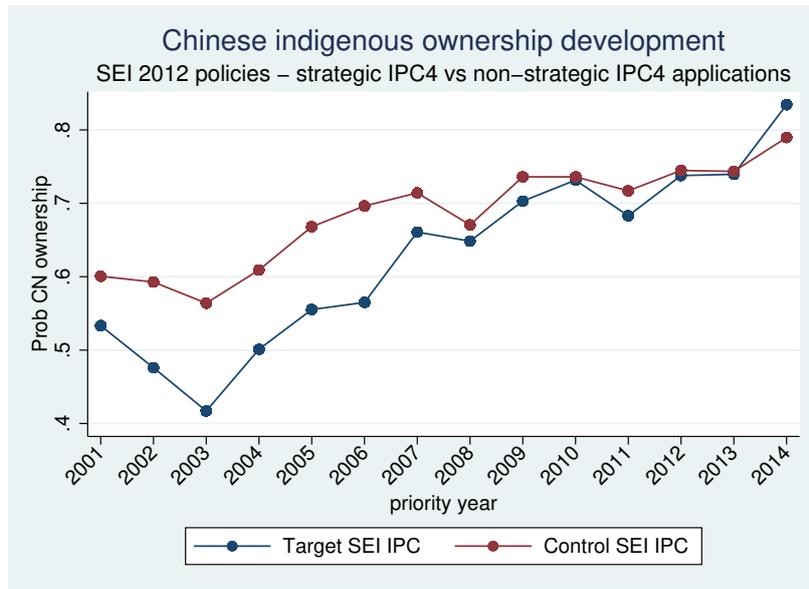


Figure 1.5: Chinese indigenous ownership development (SEI)

## 1.6 Results

### 1.6.1 Ownership of Chinese inventions

Table 8 in the Appendix presents summary statistics and Table 2 and Table 3 below presents the main results for the treatment effect of the MLP (Table 2) and the SEI plan (Table 3). As noted above, results and interpretation of the MLP analysis need to be read with a caveat due to the absence of a parallel trend before the policy measures.

In the regressions of Table 2 below for both, the linear probability model (columns 1 and 4) and the logistic model (columns 2-3 and 5-6), the coefficient of our key variable of interest, the interaction term of MLP period and Strategic IPC of the MLP, is positive and significant - pointing to a success of the policy measures with regard to increased domestic ownership. In terms of percent change the results show that the probability of Chinese ownership of a Chinese (co-) invention which belongs to an IPC4 class which was part of the targeted MLP policy plan is associated with a 4 percent increase after year 2006 compared to Chinese (co-)inventions

Dependent Variable:	(1)	(2)	(3)	(4)	(5)	(6)
Chinese ownership	LPM Coeff	Logit Coeff	Logit AME	LPM Coeff	Logit Coeff	Logit AME
MLPtime	0.106*** (0.0102)	0.472*** (0.0444)	0.0922*** (0.00865)	0.0628*** (0.00819)	0.457*** (0.0562)	0.0562*** (0.00692)
MLPStrategicIPC	0.00523 (0.0140)	-0.000699 (0.0616)	-0.000137 (0.0120)	-0.00624 (0.0111)	-0.0478 (0.0761)	-0.00589 (0.00937)
MLPtimeStrategicIPC	0.0362* (0.0141)	0.208*** (0.0620)	0.0407*** (0.0121)	0.0388*** (0.0111)	0.319*** (0.0770)	0.0392*** (0.00948)
Controls						
europct				0.0638*** (0.00540)	0.465*** (0.0380)	0.0572*** (0.00466)
IPC4_C4				-0.225*** (0.0235)	-1.720*** (0.174)	-0.212*** (0.0213)
cn_invent_only				0.706*** (0.00440)	3.729*** (0.0402)	0.459*** (0.00338)
Tech Field Fixed Effects	YES	YES	YES	YES	YES	YES
_cons	0.529*** (0.0131)	0.0811 (0.0563)		0.0163 (0.0121)	-2.859*** (0.0882)	
<i>N</i>	43579	43579	43579	43579	43579	43579
<i>R</i> <sup>2</sup>	0.065			0.410		

Robust standard errors in parentheses

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

**Table 1.2:** Estimations Treatment Effect MLP Policy (2006), 2001-2014

which are not part of the targeted IPC4 classes.

Our control variables are all significant and show the expected signs: being a PCT application is associated with an increase in the probability of Chinese ownership. Being a patent application with a higher level of competition in the respective IPC4 class is associated with a decrease in the probability of being owned by a Chinese entity. Additionally, being sourced purely by a Chinese resident inventor team is associated with an increase of the latter.

Next, in Table 3, we analyse the effect of the SEI policy in 2012 on domestic ownership, looking at the period between 2006 and 2014. For both the linear probability model (columns 1 and 4) and the logistic model (columns 2-3 and 5-6) the coefficient of the interaction term of Strategic

Dependent Variable:	(1)	(2)	(3)	(4)	(5)	(6)
Chinese ownership	LPM Coeff	Logit Coeff	Logit AME	LPM Coeff	Logit Coeff	Logit AME
SEItime	0.0374*** (0.00668)	0.201*** (0.0364)	0.0379*** (0.00685)	0.0145** (0.00546)	0.125** (0.0464)	0.0149** (0.00553)
SEIstrategicIPC	-0.0534*** (0.00644)	-0.283*** (0.0336)	-0.0533*** (0.00633)	-0.0417*** (0.00518)	-0.360*** (0.0433)	-0.0429*** (0.00516)
SEItimeXstrategicIPC	0.0198* (0.00903)	0.0999* (0.0487)	0.0188* (0.00919)	0.0287*** (0.00723)	0.242*** (0.0612)	0.0289*** (0.00730)
Controls						
europct				0.0488*** (0.00582)	0.376*** (0.0434)	0.0449*** (0.00516)
IPC4_C4				-0.187*** (0.0254)	-1.502*** (0.192)	-0.179*** (0.0229)
cn_invent_only				0.706*** (0.00487)	3.702*** (0.0428)	0.442*** (0.00357)
MLPstrategicIPC				0.0401*** (0.00555)	0.343*** (0.0463)	0.0409*** (0.00551)
Tech Field Fixed Effects	YES	YES	YES	YES	YES	YES
_cons	0.631*** (0.0105)	0.532*** (0.0463)		0.0722*** (0.0115)	-2.441*** (0.0862)	
<i>N</i>	38117	38117	38117	38117	38117	38117
<i>R</i> <sup>2</sup>	0.064			0.407		

Robust standard errors in parentheses

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ **Table 1.3:** Estimations Treatment Effect SEI Policy (2012), 2006-2014

IPC and SEI Period is positive and significant. The policy measures of the SEI seem to have led to an increased ownership in its targeted technology classes. Read in percent change, the results show that the probability of Chinese ownership of a Chinese (co-)invention which belongs to an IPC4 class which was part of the targeted SEI policy plan increases by 3 percent after 2012 compared to Chinese (co-)inventions which are not part of the targeted IPC4 classes.

## 1.6.2 Quality of Chinese inventions

In this subsection we turn to the testing of hypothesis two, in which we are interested in the potential change in characteristics and value indicators of the Chinese inventions which might have been a consequence of the SEI policy plan. The aim here is to estimate if there has been an effect on the quality of the inventions in the strategic technologies targeted versus the technologies which were not targeted.

We employ the same methodology as in the previous chapter and use a difference-in-differences approach. Given the count data nature of the different depending variables that can proxy for patent quality, we choose to use the Poisson quasi maximum likelihood estimation technique.

Throughout the analysis, we use four separate indicators, namely the number of forward citations received in a five years window, the number of claims, the number of backward citations and the family size of the Chinese patent applications with Chinese inventors or co-inventors. *Forward Citations*, i.e. a higher number of received citations by other patent filings can be an indication of the impact, technological importance for subsequent technologies and implied economic value of an invention (Trajtenberg, 1990; Hall et al., 2005; Harhoff et al., 2003). *Claims* may not only correspond to the technological breath of the patent but also to the breath of the rights conferred to its holder and occurring fees for the holder with an increasing number of claims. More claims can hence indicate a higher expected market value (Lanjouw and Schankerman, 2004; Tong and Davidson Frame, 1994). *Backward Citations* are another valid proxy for patent quality as they inform on the investigation in and dynamics of the inventive process. A larger number of backward citations were found to point at a higher value of patent (Harhoff et al., 2003; Squicciarini et al., 2013a). *Family size* stands for the number of patent offices that the patent has been filed at. A higher number of patent offices suggests a higher value of the patent since it reflects the geographical scope that the applicant has been targeting for patent protection (Grupp and Schmoch,

1999; Squicciarini et al., 2013a).

For controls, we include again the filing route and whether or not the invention is developed by a purely Chinese inventor team as both are expected to have simultaneous effects on the quality indicators of the patent application. According to Thoma (2013), differences in quality indicators of EPO patents suggest a lower quality for patents with Chinese inventors and Chinese applicants compared to patents without Chinese involvement. Additionally, for the analysis of the SEI, we include a dummy that controls for whether a IPC technology subclass is concerned that had been treated at the MLP already before. Further, we include fixed effects for technology classes on the 35 WIPO technology fields level in all regressions.

Table 4 below presents the results of our estimations: namely, the effect on patent quality as measured in forward citations, backward citations, claims and family size. In the case of forward citations, we use a citation window of five years and therefore restrict our regression for this dependent variable to the years 2001 to 2010. Regressions for the number of claims and family size are performed for the full sample from 2001 to 2014. Further, not all of the (most recent published) Chinese applications with Chinese inventor or co-inventor in our EPO dataset were present in the last OECD Patent Quality and OECD Citations dataset. This led to different number of total observations. Hence, the total number of observations for the dependent variable of number of claims (N=43,579) is larger than the one for the family size of the patent application (N=37,203) and it needs to be taken into account when interpreting the regression results.

Our key coefficient of interest, the DiD estimator and coefficient of the interaction term  $MLP_{timexStrategicIPC}$ , shows different results for the three patent characteristics analyzed. A negative and statistically significant effect is found for claims but no significant change can be found for forward citations and family size. With regard to the MLP, hypothesis two is therefore confirmed for the patent quality proxy claims and no

Dependent Variable	(1) Forward Citations	(2) Forward Citations	(3) Claims	(4) Claims	(5) Family Size	(6) Family Size
MLPtime	-0.303*** (0.0601)	-0.276*** (0.0600)	-0.208*** (0.0136)	-0.197*** (0.0134)	-0.209*** (0.0125)	-0.207*** (0.0120)
MLPStrategicIPC	0.104 (0.0726)	0.114 (0.0724)	0.0884*** (0.0195)	0.0891*** (0.0191)	0.0335* (0.0165)	0.0246 (0.0160)
MLPtimeStrategicIPC	-0.118 (0.0756)	-0.101 (0.0754)	-0.0492** (0.0189)	-0.0489** (0.0185)	0.00717 (0.0166)	0.00656 (0.0162)
Controls						
europct		-0.117** (0.0384)		-0.000953 (0.00659)		0.170*** (0.00773)
cn_invent_only		-0.595*** (0.0370)		-0.184*** (0.00613)		-0.226*** (0.00858)
Tech Field Fixed Effects	YES	YES	YES	YES	YES	YES
_cons	-0.939*** (0.137)	-0.409** (0.140)	3.001*** (0.0667)	3.099*** (0.0669)	1.745*** (0.0530)	1.727*** (0.0528)
N	22255	22255	43579	43579	37203	37203

Note: Regressions performed with Poisson Quasi Maximum Likelihood estimation.

For forward citations, a citation window of five years is used and estimations restricted to years 2001 to 2010.

Estimations for claims and family size performed for the full sample from 2001 to 2014.

Robust standard errors in parentheses

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

**Table 1.4:** Estimations of effect of Medium- and Long-Term Program for Science and Technology Development (MLP) policy (2006) on patent quality, 2001-2014

negative significant association was found when measuring quality with the indicators forward citations (until 2010) and the family size.

Finally, we look at the potential effect of the SEI policy on patent quality. Here we cannot use forward citations and citation time window because we are interested in more recent years (post 2012), for which such information is not yet available. We therefore include backward citations instead. As noted above, not all of the Chinese applications with Chinese inventor or co-inventor in our EPO dataset were present in the OECD Patent Quality and OECD Citations dataset. We therefore have different number of total observations for the dependent variable of number of claims ( $N=38,117$ ) and the number of backward citations as well as family size of the patent ( $N=31,741$ ). This needs to be taken into account when interpreting the results.

Dependent Variable	(1) Backward Citations	(2) Backward Citations	(3) Claims	(4) Claims	(5) Family Size	(6) Family Size
SEItime	-0.101*** (0.0134)	-0.0455*** (0.0128)	0.00530 (0.00588)	0.0113 (0.00584)	-0.0942*** (0.00983)	-0.0690*** (0.00973)
SEIStrategicIPC	0.0234* (0.0119)	-0.00455 (0.0110)	0.0312*** (0.00553)	0.0201*** (0.00557)	0.0329*** (0.00790)	0.0145 (0.00770)
SEItimeXStrategicIPC	0.0946*** (0.0249)	0.0661** (0.0244)	0.0164* (0.00773)	0.0142 (0.00766)	0.0626*** (0.0135)	0.0514*** (0.0132)
Controls						
europct		0.564*** (0.0130)		-0.0190** (0.00601)		0.145*** (0.00837)
cn_invent_only		0.0257 (0.0235)		-0.139*** (0.00544)		-0.230*** (0.00985)
MLPStrategicIPC		0.0314* (0.0145)		0.0390*** (0.00575)		0.0217* (0.00927)
Tech Field Fixed Effects	YES	YES	YES	YES	YES	YES
_cons	1.889*** (0.0291)	1.476*** (0.0326)	2.493*** (0.0407)	2.598*** (0.0388)	1.588*** (0.0695)	1.560*** (0.0705)
<i>N</i>	31741	31741	38117	38117	31741	31741

Note: Regressions performed with Poisson Quasi Maximum Likelihood estimation.

Robust standard errors in parentheses

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

**Table 1.5:** Estimations of effect of the 12th Five-Year National Development Plan of Strategic Emerging Industries (SEI) policy (2012) on patent quality, 2006-2014

Results of our estimations are presented in Table 5 below. The coefficient of the interaction term SEItimeXStrategicIPC, shows a positive association with all three patent characteristics analyzed. A statistically significant effect is found for backward citations and family size. The positive relationship between the interaction term and these two patent quality indicators is the opposite of the relationship formulated in hypothesis two.

The results suggest that Chinese patent applications with Chinese inventors or co-inventors in the targeted technologies have been of higher quality (as measured in backward citations and family size of the application) than in the non targeted technologies after the implementation of the SEI. More specifically, inventions in the targeted technologies, compared to non-targeted ones, are expected to have 7% more backward citations and 5% premium with regard to the family size of the Chinese invention, i.e.

the number of patent offices in which the invention is filed at, after the implementation of the SEI plan. Further, it is also positive for the number of claims but insignificant including our controls.

## **1.7 Conclusion**

China has the firm goal to become technologically less dependent from foreign powers and establish its own innovative capacities on its designed path to a innovation-driven economy and society. The two major political initiatives and directives of this attempt over the past fifteen years are the indigenous innovation policies formulated in detail in the National Medium- and Long-Term Program for Science and Technology Development (MLP) and the 12th Five-Year National Development Plan of Strategic Emerging Industries (SEI). Both shared the main goal to develop and increase ownership of intellectual property in technology classes that the Chinese government considers key for the future development of its country. This article shed light on the two plans and their goals and explored them with regard to their overseas patenting.

We employed a difference-in-differences approach to test whether China increasingly owns its indigenous inventions in the targeted technology fields by looking at developments in Chinese as opposed to foreign ownership of patents which involve Chinese inventors. Our results indicate that the various measures taken led to an increase of Chinese ownership in indigenous inventions which were favored by the MLP and the SEI.

In a second line of investigation, our data and approach chosen allowed us to look at the potential effects of the policy measures on different characteristics and value of the applications which indicate quality aspects of them. Here we find indications that despite the criticism of the quality and value of Chinese inventions that it might have improved after the reforms, at least for patents in technology fields targeted by the SEI. This is documented by an increased number of backward citations and family

size in targeted technologies in the SEI vis-à-vis non targeted ones after its implementation.

## 2

# Going Out to Innovate More at Home: Impacts of Outward Direct Investments on Chinese Firms' Domestic Innovation Performance<sup>1</sup>

Outward-going direct investment (ODI) from China has seen a sharp increase since the early 2000s, coinciding with accession to the World Trade Organization (WTO) and the start of its “going out” strategy. Since entering the WTO, China (including Hong Kong) has risen to become the world’s second largest investor with \$183 billion ODI in 2015 according to UNCTAD figures, second only to the US (\$300bn in ODI)<sup>2</sup>. Over the past

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<sup>2</sup>See United Nations Conference on Trade and Investment Division (UNCTAD), Global Investment Monitor 2016.

10 years, the annual growth rate of Chinese investments has been more than 30%<sup>3</sup>. This high growth trend is likely to continue as President Xi Jinping announced on numerous occasions that China will make around \$750 billion in foreign direct investments until 2020<sup>4</sup>.

In the early 2000s, Chinese firms tended to target resource-rich countries primarily in Africa in order to secure better access to natural resources and the emerging markets. Following the global financial crisis, however, the nature of China's ODI behavior shifted dramatically towards targeting developed economies on its quest to acquire strategic assets and promote rapid technological scale up. The majority of the Chinese direct investments abroad targeting developed economies mainly consist of merger and acquisition (M&A) deals. According to the Rhodium Group, for instance, only 9% of the \$106 billion Chinese direct investments into the US between 2000 and 2016 stem from greenfield investment and less than 5% of the \$20,6 billion ODI invested in the EU in the fourth quarter of 2016.<sup>5 6</sup>

There is a substantial and growing literature on the patterns, drivers and "waves" of ODI from emerging economies (Gammeltoft and Kokko, 2013; Lebedev et al., 2014; Sauvart, 2005; Sauvart et al., 2009). In the Chinese context, studies show that the motives behind Chinese companies ODI behavior is at least partially driven by their quest to gain access to resources, markets, know-how, high-tech and economies of scale and scope (Boateng et al., 2008; Buckley et al., 2007; Deng, 2009). Often incentivized and substantially subsidized by the Chinese government, Chinese entities increasingly invest in developed economies in search of strategic assets and rapid technological scale up (Amighini et al., 2013; Deng, 2007, 2009; Di Minin et al., 2012; Duysters et al., 2009; Huang and Wang, 2013; Peng, 2012; Rui and Yip, 2008; Spigarelli et al., 2013).

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<sup>3</sup>See MOFCOM, China's Outward Investment and Economic Cooperation 2015.

<sup>4</sup> President Xi made this announcement at the Asia-Pacific Economic Cooperation (APEC) Summit 2016 as well as at the World Economic Forum (WEF) 2017.

<sup>5</sup>See Rhodium Group China Investment Monitor 2017

<sup>6</sup>See Rhodium Group EU-China FDI Monitor 2016 4Q Update

Most of the existing literature, however, that assigns a strategic asset-seeking motive to Chinese ODI behavior is based on theoretical arguments or individual case studies rather than empirical-based evidence (Deng, 2013).

Some studies, for instance, argue that ODI is used by firms from emerging economies, in particular from China, to employ the newly won technological capabilities resulting from the M&A for competition in their own domestic market (Child and Rodrigues, 2005; Luo and Tung, 2007; Matthews, 2006; Ramamurti, 2012). This line of thinking supports the idea that the timing of China's rapid ODI targeted in developed economies coincides with China's commitment to rebalancing its economy towards a 'New Normal,' which places the role of innovation and promotion of strategic emerging industries at the forefront of its attempts to transition from an investment-driven growth model to one driven by innovation<sup>7</sup>.

To the best of our knowledge, however, there is no empirical study which examines the impact of Chinese cross-border mergers and acquisitions (M&A) in terms of post-deal domestic innovation performance at the firm-level and by patent analysis. We aim at filling this gap in the literature and advance our understanding of how Chinese firms cross-border M&A behavior impacts their subsequent innovation performance within China. In particular, we seek to address some crucial questions regarding whether, when and how Chinese overseas M&As lead to the desired innovation outcomes at home.

To this end, we construct a new firm-level data set that combines information from the WIND database and the Zephyr database from Bureau van Dijk. That is we link the general business and financial information, including R&D spending, for all companies listed at China's A-share stock exchange markets at Shanghai and Shenzhen from WIND with all

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<sup>7</sup>China's recent explosion in patenting activities offers evidence of its attempts to rapidly improve its innovation capabilities, i.e. Chinese domestic invention patent applications exploded from 50,000 in 1999 to 825,000 in 2013, making the State Intellectual Property Office the largest filing office in the world today (Wunsch-Vincent et al., 2015).

cross-border, majority M&A deals of these firms contained in the Zephyr database. We then add the domestic invention patent portfolios, including claims information, of the listed firms to the dataset, using public patent information of the State Intellectual Property Office of China (SIPO).

It is acknowledged upfront that firms that engage in cross-border M&A are likely to be systematically different than firms that do not, which makes it difficult to identify the causal effect of cross-border M&A on innovation due to potential selection bias. To deal with this issue, Propensity-Score-Matching (PSM) techniques are combined with the difference-in-differences estimator (PSM-DiD). The PSM-DiD identification strategy is common in the literature, in part, because the matching procedure helps ensure comparability between the treatment and control groups, while the DiD estimator accounts for time-invariant unobservable firm heterogeneity which is neglected by PSM. In addition, due to some recent criticism about PSM (King and Nielsen, 2016), alternative matching techniques are also used as a robustness check.

## **2.1 Literature Review**

The economic literature dealing with the impact of M&A on innovation performance of the merged entity leaves mixed results. Theoretically, the net effect of mergers and acquisitions is ambiguous. There are various possible effects that the merge with or acquisition of another firm can have on R&D performance of the merged entity. As Veugelers (2006) explains, M&A deals might, through efficiency and competition motives in R&D as well as in the output market, lead to an increase or a decrease in R&D inputs and R&D performance due to the existence of economies of scale and scope, as well as an increase in market power.

Empirical studies that looked into the effects of mergers and acquisitions on innovation performance have found mixed results. For example, while (Stiebale, 2013), analyzing foreign M&As of German SMEs, finds that

firms show more domestic spending for R&D after cross-border acquisition, Bertrand and Zuniga (2006) do not find a significant positive relationship between M&As and R&D investment when investigating domestic and cross-border M&As effects on R&D at the industry level in France.

Previous studies focusing on the effects of M&As on economic performance such as profitability have yielded inconsistent results, too. While some analyses find a positive average impact (Healy et al., 1992), others report post-M&A losses in firms' operating performance (Yeh and Hoshino, 2002; Bertrand and Betschinger, 2012) or suggest contrasting results (King et al., 2004; Tuch and O'Sullivan, 2007; Sharma and Ho, 2002; Ghosh, 2001)

With respect to studies focusing on China, (Edamura et al., 2014) analyze a total of 46 M&A deals between 2007 and 2011 and show that Chinese outbound M&As led to an increase in overall sales, fixed and intangible assets and productivity, despite finding no significant effect on the change in R&D intensity. Besides only the small sample size, the authors also restrict the sample to knowledge-intensive industries, and the results are not necessarily generalizable. In another study, Cozza et al. (2015) consider international M&As and Greenfield investments by Chinese companies in advanced European countries between 2003 and 2011. The authors find a positive impact of such deals on labour and total factor productivity of the companies, but a decrease firms' profit margin and return on assets as defined as earnings before interest and tax (EBIT) over total assets. (Fu et al., 2018) investigate the link between ODI and innovation performance through a purpose-designed survey and cross check telephone interviews of Chinese firms in the province of Guangdong between 2007 and 2009. Taking new product sales and self-declared innovator status as dependent variables, the authors' results indicate that conducting ODI yields increased innovation performance but only when directed to developed markets. Further, R&D expenditures are shown to contribute directly to new product sales and overall, SOEs appear less innovative than firms with different ownership forms. Gugler and Vanoli (2015) perform a patent and citation analysis of Chinese multinationals' European subsidiaries' patents

registered at the European Patent Office. Investigating the linkages between and contribution of foreign and domestic firms in the citations of these patents, the findings of the authors suggest that the merge with or acquisition of firms abroad has only a limited impact on Chinese companies' innovation output and that the M&A did not lead to an upgrade in innovation capabilities.

## **2.2 Data Sources Key Variables**

The analysis in this study is based on a new firm level data set constructed with the following three main data sources linked for this purpose.

First, we rely on the Zephyr database, Bureau van Dijk's global M&A information tool to obtain all deal information on overseas mergers and acquisitions from companies in China. The Zephyr database has been commonly used in the literature on the effects of M&A (Amendolagine et al., 2015; Cozza et al., 2015; Grimpe and Hussinger, 2008; Stiebale, 2016), and unlike other M&A databases, e.g. SDC Platinum, it includes M&A deals below 10 million USD.

Next, we rely on the WIND database to obtain the general business and financial information for all companies listed at China's A-share stock exchange markets at Shanghai and Shenzhen. Together, the stock exchanges combine more than 3000 companies (3,111 in our dataset). Combined, these two major stock exchanges of mainland China, have increased their listed companies from over 1,000 in the year 2000 (then corresponding to a market capitalization of almost a third of China's GDP (Seddighi and Nian, Seddighi and Nian), to more than 3,000 firms in the year 2016 (then worth a market capitalization of more than 65% of China's GDP) <sup>8</sup>. WIND is one of most used and comprehensive databases for listed companies in China, and includes an unusually extensive list of variables, including

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<sup>8</sup>See World Bank Open Data 2018

information on employment, total sales, gross output, geographic location, industry, R&D spending, affiliation, financial structure, and so forth.

Finally, we obtain patent information from the INCOPAT database, which provides all of the public patent information collected by SIPO including the domestic invention patent portfolios of the listed Chinese firms in our sample. In addition to the number of invention patent applications and number of granted applications, INCOPAT also provides additional information about the individual patents' citations and claims. In line with the literature (Hall et al., 2005; Squicciarini et al., 2013a) on patent quality, the citations and claims information can be used to measure the value and characteristics of the firms' patents which reflect their impact and quality. Forward citations received are a commonly used and robust indicator for the impact and value of a patent in the pertinent literature (Trajtenberg, 1990; Hall et al., 2005; Webb et al., 2005). The claims of a patent are listed by the patent assignee(s) in their patent application and relate to the scope and breadth of the invention that they want to protect. A larger number can indicate a higher technological value and expected market value (Lanjouw and Schankerman, 2004; Tong and Davidson Frame, 1994; Squicciarini et al., 2013a). However, it can also be argued that patents of lower quality might potentially be substantiated by including more claims in the application, a potential shortcoming that one needs to be aware of when using claims. While there exist a number of other patent quality indicator proxies in the literature such as the lifespan and the family size (number of jurisdictions that the application is filed at) of a patent, the number of citations and the number of claims are the ones we can obtain from the patent database. We complete our combined dataset with them.

### **2.2.1 Data Cleaning and Merges**

As the first step, we clean the retrieved cross-border M&A deals data for all cross-border M&A from mainland China from 2001 to mid 2016 recorded in the commercial M&A database Zephyr. Zephyr also includes

information on deal statuses like rumours, pending or announcements and for the purpose of our study, we only consider deals which are considered completed or completed assumed. A 10% ownership threshold is used to define a cross-border M&A, meaning that we only consider acquisitions or mergers which lead to a stake of at least 10% in the acquired company for the acquirer. Further, we exclude all other deal types, including "Joint Ventures", from our sample, leading to a total count of 2,054 cross-border M&A by Chinese companies since 2001.

We then match the general business and financial information for all companies listed at China's major stock exchange markets at Shanghai and Shenzhen in the WIND database with these cross-border M&A deals of the firms via firm name. This matching is done by computer matching, i.e. "fuzzy lookup", which was found to yield a higher correct matching rate than Stata's fuzzy matching commands. The algorithmic matching is subsequently complemented by manual checks of the automatic matches as well as of every cross-border M&A case which was not automatically matched in order to guarantee the highest matching rate possible. The individual manual check of every deal allows us to identify and include deals in our analysis where the acquirer is a parent (20 cases) or subsidiary (48 cases) firm of the listed firm. Further, for the purpose of this study we exclude multiple deals per year and per firm, leaving only the deal with the maximum deal value in the sample in case there were several deals per year and per firm (53 cases), leading to a sample of 373 cross-border M&A as defined above of listed Chinese companies since 2001.

Next, we merge the domestic invention patent portfolios of the firms to the dataset, using public patent information of SIPO from the INCOPAT database, including the individual patents' claims, adding valuable additional information on the quality of firms' patents to the dataset. Initially also considering forward citations, we need to drop this additional impact indicator due to data truncation found not allowing for the construction of a suitable citation time window. Because of limited data availability of several variables which are key to our subsequent analysis in the WIND

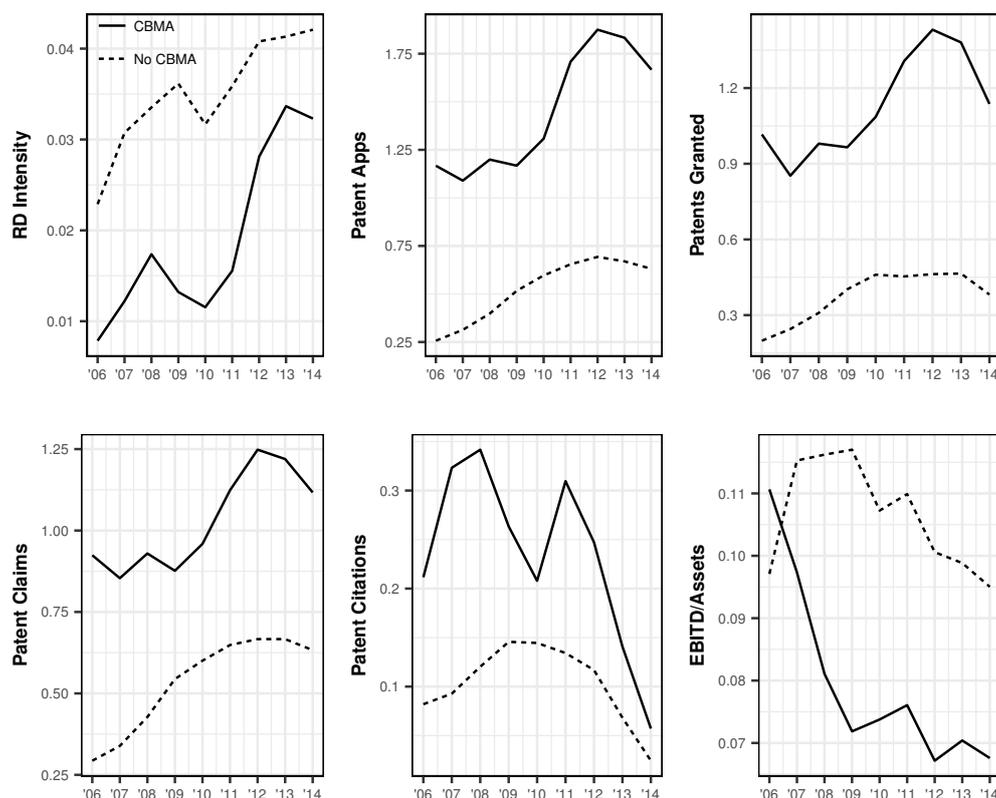
database such as firms' R&D expenditures (available only from 2006) and patent data truncation, we limit our final sample to cross-border M&A between 2006 and 2014.

## **2.2.2 Dependent Variables**

We are interested in studying the cross-border M&A effects on firms' innovation and economic performance. Specifically, we estimate the cross-border M&A effects on innovation efforts, proxied by innovation spending. Innovation spending is defined as R&D intensity calculated as the ratio of R&D expenditures of a firm to its total operating revenue. Next, we estimate the cross-border M&A effects on innovation performance, proxied by patent applications and patents granted. These innovation output measures correspond to innovation quantity. It is also of interest to study the cross-border M&A effects on innovation quality, for which we use the number of claims in the patent application as proxy. Finally, we look at the cross-border M&A effects on financial performance, proxied by firms' earnings before interest, taxes, depreciation and amortization (EBITDA) divided by firms' total assets.

## **2.2.3 Independent Variables**

The main variable of interest is whether or not a firm engages in overseas direct investments. Based on the available information in Zephyr database, we distinguish between cross-border M&A and non-cross-border M&A firms based on whether or not a firm has successfully completed a cross-border M&A. Besides the cross-border M&A dummy variable, we also rely on a set of additional firm-level covariates from the WIND database as controls. These include the firm's knowledge stock, ownership status, number of employees, operating revenues, fixed assets, and intangible assets. See Tables A1 and A2 in the appendix for a summary of the main variables and a correlation coefficient matrix.



**Figure 2.1:** Comparison of innovation and financial performance of Chinese listed firms with and without cross-border M&A (2006-2014), figures in logarithmic form

Figure 1 presents the innovation and financial performance outcomes over time for cross-border M&A and non-cross-border M&A firms. Starting in 2006, there is a wide gap in the reported levels of R&D spending between firms with and without a cross-border M&A. This gap narrows substantially over time, showing that cross-border M&A firms increased R&D spending to a greater extent over the time period. The additional plots show that cross-border M&A firms exhibited superior innovation performance (both quantity and quality) and but lower financial performance compared to non-cross-border M&A firms. The gap between cross-border M&A and non-cross-border M&A firms across the different innovation proxies remained consistently large across the sample period.

### 2.3 Estimation Strategy and Identification

To study the cross-border M&A effects on firms' innovation and economic performance, the general basic specification is as follows,

$$y_{it} = \alpha_0 + \alpha_1 CBMA_{it} + \alpha_2 \mathbf{Z}_{it} + w_i + v_t + \epsilon_{it} \quad (2.1)$$

where  $y_{it}$  is an outcome variable of interest related to innovation inputs, outputs, or financial performance of firm  $i$  in year  $t$ .  $CBMA_{it}$  is a binary variable that equals 1 if firm  $i$  successfully completed a cross-border M&A in year  $t$ , and 0 otherwise.  $\mathbf{Z}_{it}$  includes a set of covariates, and  $w_i$  and  $v_t$  are a set of firm and time fixed effects, and  $\epsilon_{it}$  is an error term.

It is acknowledged, however, that firms that engage in cross-border M&A may systematically differ from those firms that do not. The potential selection effects make it difficult to identify the causal effects of cross-border M&A on domestic innovation. To help reduce selection bias, we rely on a PSM-DiD identification strategy which has been used previously in the pertinent literature to study effects of ODI on innovation in similar contexts (Bertrand, 2009; Cozza et al., 2015; Edamura et al., 2014; Stiebale and Trax, 2011; Stiebale and Reize, 2011).

The PSM-DiD approach is carried out in two stages. In the first stage, a nonlinear propensity score matching technique is used to construct a control group of firms that match most closely to treated firms based on observable characteristics. A list of covariates is developed in order to identify the most appropriate control group. The covariates selected include a range of variables that help to control for various dimensions of firms' performance. Firms in the control group are matched those in the treatment group based on the pre-treatment mean of these variables (prior to the firm completing its first cross-border merger or acquisition). In second stage, a difference-in-differences method takes care of any time-invariant fixed firm effects, and estimates the effect of cross-border M&A

on relevant outcomes of the firms that engage in cross-border M&A.

Our estimation strategy is given as follows:

$$Y_i^s = \beta_0 + \delta After_i^s + \beta_1 CBMA_i + \delta_1 (After_i^s \times CBMA_i) + \theta X_i + \mu_i^s \quad (2.2)$$

where the dependent variable  $Y_i^s$  is the outcome variable of interest for firm  $i$  in  $s$  years after the completion of a cross-border M&A, with the delay  $s$  ranging from 0 to 3. The variable  $After$  denotes a dummy variable for the second time period (post cross-border M&A), ranging from year 0 to 3 after a cross-border M&A completion.  $CBMA_i$  is a time-invariant dummy that equals to 1 for firms that have engaged into a cross-border M&A and 0 otherwise.  $X_i$  is a vector of pre-treatment control variables for firm  $i$ .  $\mu_i^s$  is an error term.

We now turn to our empirical implementation.

First, a probit model is employed to see if the chosen covariates are actually important determinants of whether or not the firm engages into cross-border M&A whichever the time period. The probit model is expressed as:

$$P(D_{it}) = \alpha_0 + \alpha_1 \mathbf{Z}_{it} + \epsilon_{it} \quad (2.3)$$

where  $D_{it}$  is a dummy that equals to 1 if the firm  $i$  has an cross-border M&A deal in year  $t$ .  $\mathbf{Z}_{it}$  includes a set of covariates and  $\epsilon_{it}$  is an error term. Table 1 reports the results from the estimation of the probit model. Column (1) includes the firm covariates, year fixed effects are included in Column (2), and industry fixed effects for the acquirer and target cross-border M&A are added in Columns (3) and (4), respectively. The main objective here is to first check whether the selected covariates are important determinants of completing a cross-border M&A.

Across each specification, the results show that the covariates are indeed statistically significant. Firms that are more likely to complete a cross-border M&A have a higher patent knowledge stock, are owned by the

	<i>Treatment</i>			
	<i>(1 if firm has cross-border M&amp;A, 0 otherwise)</i>			
	(1)	(2)	(3)	(4)
Patent Stock	0.016*** (0.001)	0.015*** (0.001)	0.004*** (0.000)	0.003*** (0.000)
SOE (0=No, 1=Yes),	0.006* (0.002)	0.009*** (0.002)	0.003*** (0.001)	0.002*** (0.001)
No. Employee	0.006*** (0.001)	0.007*** (0.001)	0.002* (0.001)	0.002** (0.001)
Operating Revenue	0.017*** (0.001)	0.016*** (0.001)	0.005*** (0.001)	0.005*** (0.001)
Fixed Assets	0.002* (0.001)	0.003* (0.001)	0.002* (0.001)	0.002* (0.001)
Intangible Assets	0.004*** (0.001)	0.003*** (0.001)	0.001*** (0.000)	0.001*** (0.000)
Year FE	No	Yes	Yes	Yes
Acquirer Industry FE	No	No	Yes	Yes
Target Industry FE	No	No	No	Yes
Log Likelihood	8245.017	8275.684	29753.976	30455.564
No Firms	3111	3111	3111	3111

Notes: \*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$ .

**Table 2.1:** Determinants of cross-border M&As

state, are larger in size, have higher operating revenue, and more fixed and intangible assets are respectively. These results are consistent with expectations that cross-border M&A firms tend to be better performing firms and related to State Owned Enterprises (SOEs).

Second, based on the above determinants, a matched control group is constructed in order to compare those firms with treated firms. Matching is based on k-nearest neighbor approach. To assess the credibility of the matching procedure, a formal pairwise t-test comparison between the treated and matched control firms is used to see whether there are any significant differences. Table 2 shows the pre-treatment means of the determinants between the treated and matched groups. The p-values from the t-test are sufficiently high across all different covariates, indicating that any systematic differences are removed in the distributions of covariates between control and treatment groups. Following the common support

	Mean		t-test	
	Treated	Matched	t-statistic	p.value
Patent Stock	2.506	2.601	-1.018	0.309
SOE (0=No, 1=Yes),	0.649	0.656	-0.407	0.684
No. Employee	8.822	8.817	0.082	0.935
Operating Revenue	22.712	22.764	-0.685	0.494
Fixed Assets	21.463	21.514	-0.645	0.519
Intangible Assets	19.611	19.683	-0.860	0.390

Notes: Propensity score matching method using nearest neighbor is applied to test whether there is no significant difference between treated and matched groups on potential determinants of cross-border merger & acquisition.

**Table 2.2:** Balancing tests for propensity score matching

condition, focus is placed on the matched firms that fall within the support of the propensity score distribution of the treated group.

The results thus show that the matching procedure provides an appropriate foundation for the DiD estimation. The DiD estimator is used to help remove the time-invariant unobserved heterogeneity across firms, such as industry specific effects and managerial skill, which is neglected in the previous matching stage. The dependent variable(s) is first differenced by calculating the difference between the post-treatment and pre-treatment means, meaning that only a balanced sample of firms are observed both before and after the treatment are kept in the sample. The DiD estimator is as follows:

$$\hat{\beta}_{DD}^s = \frac{1}{n} \sum_{i \in I_1 \cap S_p} \left[ Y_{it}^s - Y_{it-1}^s - \sum_{r \in I_0 \cap S_p} W(P_{it}, P_{rt})(Y_{rt}^s - Y_{rt-1}^s) \right] \quad (2.4)$$

where  $\hat{\beta}_{DD}^s$  is the estimator of the causal effect of cross-border M&A with  $s$  in  $s$  years after the completion of a cross-border M&A, with the delay  $s$  ranging from 0 to 3.  $i \in I_1 \cap S_p$  is a firm belonging to the set of treated firms ( $I_1$ ) that fall within common support  $S_p$ .  $r \in I_0 \cap S_p$  is a firm belonging to the set of control firms ( $I_0$ ) that fall within common support  $S_p$ .  $n$  is the

number of treated firms in the common support set  $S_p$ .  $W(\cdot)$  is a Gaussian kernel weighting function that depends on the propensity score distance between the treated and control firms.  $Y$  is the dependent variable and  $P$  measures the probability of receiving treatment based on the vector of firm characteristics ( $Z_{it-1}$ ), expressed as:  $P_{it} = E(D_{it} = 1|Z_{it-1})$ .

A key assumption of the DiD estimator is that the pre-treatment trends in the control and treated groups would be the same in the absence of treatment. To test whether the parallel trends assumption holds, variants of equation (1) above are estimated with a full set of controls to check the similarity of the pre-trends for each outcome variable of interest. The reference year is the year before a change in treatment takes place. The results support the parallel trend assumption (See Table A3 in the appendix for the results), failing to find any statistical difference in the respective outcome variables of interest between control and treated groups prior to treatment.

A second issue that arises relates to the quality of matching. Despite the popularity of propensity score matching in the literature, it is acknowledged that propensity scores are criticized in the recent literature due to several drawbacks (King and Nielsen, 2016). Therefore, as a robustness check, an alternative matching technique – Coarsened Exact Matching (CEM) – is employed in addition to the more popular propensity exact matching (PSM). In cases when bias arises, CEM is shown to yield less biased estimates of the causal effect across different sample sizes as compared to PSM (Iacus et al., 2012, 2011). Different to PSM, which optimally minimizes the expected mean imbalance when all treated units are matched, CEM coarsens the covariates into intervals, prunes observations that would have led to large extrapolations and reduces maximum imbalances. This leads to lower bias and a better sample average treatment effect estimation than propensity score matching and other matching methods Iacus et al. (2012, 2011).

Finally, although we do our best to mitigate potential endogeneity with

the steps described above and performed robustness checks with CEM, the likely self selection of engaging into cross-border M&A cannot be fully overcome. That is, firms that opt for cross-border M&A might have, for example, better access to market information, benefit from better governance, are superior innovation growth firms or have better access to financing. These are all time-variant characteristics which remain unobserved and which cannot be taken into by account by the propensity score matching nor the difference-in-differences. This is a problem common in the pertinent literature that seeks to assess the performance effects of M&As, which is extensively discussed by (Egger and Hahn, 2010). The following results should therefore be read and interpreted cautiously under these limitations.

## **2.4 Results**

In this section, we compute the average difference in outcome in several innovation indicators between acquiring firms and their respective counterfactual firms relative to the pre-acquisition year in order to measure the impact of cross-border M&A. It is estimated at different points of time, i.e. the acquisition year itself (“Treatment”), one year after the acquisition (“Post-Treatment (t+1)”), two years after the acquisition (“Post-Treatment (t+2)”) and three years after the acquisition (“Post-Treatment (t+3)”).

In our first estimation, we estimate via DiD the impact of cross-border M&A on innovation efforts proxied by R&D intensity as measured in the ratio of R&D expenditures to operating revenues. Table 3 presents the measured effect over time. cross-border M&A have a positive and statistically significant effect on R&D intensity that is immediate. Over time, the size of the effect attenuates slightly, although remains positive and significant. The results suggest that firms tend to rely on their cross-border M&A and acquired external knowledge in a way that complements in-house spending on research activities. In Panel B, the main results are

	<i>Innovation Spending (R&amp;D Intensity (ln))</i>			
	(1)	(2)	(3)	(4)
<b>Panel A: PSM (n=704)</b>				
Treatment	0.017*** (0.004)	...	...	...
Post-Treatment ( $t + 1$ )	...	0.014*** (0.002)	...	...
Post-Treatment ( $t + 2$ )	...	...	0.012*** (0.002)	...
Post-Treatment ( $t + 3$ )	...	...	...	0.012*** (0.002)
<b>Panel B: CEM (n=448)</b>				
Treatment	0.009** (0.003)	...	...	...
Post-Treatment ( $t + 1$ )	...	0.013*** (0.002)	...	...
Post-Treatment ( $t + 2$ )	...	...	0.011*** (0.002)	...
Post-Treatment ( $t + 3$ )	...	...	...	0.011*** (0.002)

Notes: \*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$ .

**Table 2.3:** PSM-DiD results: CBMA and post-CBMA impacts on innovation spending

confirmed by coarsened exact matching (CEM) that cross-border M&A has positive and persistent effects on firms' innovation efforts, although the size of the cross-border M&A effects become slightly more pronounced over time.

Next, we study the effects of cross-border M&A on firms' innovation performance, proxied by the number of domestic patent applications and patents granted. Table 4 reports the results. In Panel A, cross-border M&A has a positive and significant effect on the number of patent applications. The largest effect is observed in the year that the cross-border M&A was completed, and in the subsequent years, the size of the effect becomes attenuated. Looking at the cross-border M&A effects on patents granted, in contrast, the results indicate that cross-border M&A effects do not

become statistically significant until two years after the cross-border M&A was completed. This makes sense intuitively as firms can expect some time delay in exploiting foreign-obtained knowledge into new patentable knowledge in China. These results are largely confirmed by coarsened exact matching (CEM) in Panel B.

	Innovation Quantity							
	# of Patent Apps ( <i>ln</i> )				# of Patents Granted ( <i>ln</i> )			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<b>Panel A: PSM (n=704)</b>								
Treatment	0.745*** (0.181)	...	...	...	0.270 (0.179)	...	...	...
Post-Treatment ( <i>t</i> + 1)	...	0.290* (0.122)	...	...	...	0.150 (0.119)	...	...
Post-Treatment ( <i>t</i> + 2)	...	...	0.439*** (0.112)	...	...	...	0.253* (0.110)	...
Post-Treatment ( <i>t</i> + 3)	...	...	...	0.575*** (0.122)	...	...	...	0.455*** (0.119)
-----								
<b>Panel B: CEM (n=448)</b>								
Treatment	0.445* (0.207)	...	...	...	-0.139 (0.200)	...	...	...
Post-Treatment ( <i>t</i> + 1)	...	0.205 (0.117)	...	...	...	0.065 (0.113)	...	...
Post-Treatment ( <i>t</i> + 2)	...	...	0.420*** (0.106)	...	...	...	0.233* (0.104)	...
Post-Treatment ( <i>t</i> + 3)	...	...	...	0.584*** (0.115)	...	...	...	0.461*** (0.112)

Notes: \*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$ .

**Table 2.4:** PSM-DiD results: CBMA and post-CBMA impacts on innovation quantity

	<i>Innovation Quality</i>			
	<i># of Patent Claims (ln)</i>			
	(1)	(2)	(3)	(4)
<b>Panel A: PSM (n=704)</b>				
Treatment	0.228 (0.134)	...	...	...
Post-Treatment ( $t + 1$ )	...	0.033 (0.089)	...	...
Post-Treatment ( $t + 2$ )	...	...	0.210* (0.082)	...
Post-Treatment ( $t + 3$ )	...	...	...	0.227* (0.090)
<b>Panel B: CEM (n=448)</b>				
Treatment	0.218 (0.149)	...	...	...
Post-Treatment ( $t + 1$ )	...	-0.001 (0.084)	...	...
Post-Treatment ( $t + 2$ )	...	...	0.191* (0.077)	...
Post-Treatment ( $t + 3$ )	...	...	...	0.212* (0.084)

Notes: \*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$ .

**Table 2.5:** PSM-DiD results: CBMA and post-CBMA impacts on innovation quality

Moving beyond innovation quantity, Table 5 reports the results from estimating the effects of cross-border M&A on innovation quality. With this only indicator for patent quality at hand and its limitations mentioned above, we use the number of patent claims as the measure of innovation quality. The result suggest a positive impact on this measure of innovation quality. In Columns (1)-(4), cross-border M&A enters in as statistically significant but not until 2 years following the completion of a cross-border M&A. The size of the coefficient remains similar two and three years post-treatment suggesting a sustained improvement on firms' innovation quality as measured by patent claims.

As an additional test, we next look at the cross-border M&A effects on firms' financial performance, in this case, proxied by EBITDA divided by

	<i>EBITDA/Assets (ln)</i>			
	(1)	(2)	(3)	(4)
<b>Panel A: PSM (n=704)</b>				
Treatment	-0.483*** (0.116)	...	...	...
Post-Treatment ( $t + 1$ )	...	-0.342*** (0.077)	...	...
Post-Treatment ( $t + 2$ )	...	...	-0.226** (0.072)	...
Post-Treatment ( $t + 3$ )	...	...	...	-0.287*** (0.079)
<b>Panel B: CEM (n=448)</b>				
Treatment	-0.333** (0.121)	...	...	...
Post-Treatment ( $t + 1$ )	...	-0.297*** (0.068)	...	...
Post-Treatment ( $t + 2$ )	...	...	-0.215*** (0.063)	...
Post-Treatment ( $t + 3$ )	...	...	...	-0.284*** (0.068)

Notes: \*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$ .

**Table 2.6:** PSM-DiD results: CBMA and post-CBMA impacts on financial performance

the firms' total assets. Based on the coefficients, cross-border M&A has a negative and statistically significant immediate effect on firms' financial performance. As shown in the remaining columns these negative effects persist over time, indicating that cross-border M&A lead to a sustained lower financial performance in the years following the completion of the M&A deal. These results are similar to earlier ones found in Cozza et al. (2015).

## 2.5 Conclusion

This study examined the effects of Chinese outward direct investments, proxied by the completion of a cross-border merger or acquisition, on

the innovation and economic performance of Chinese listed companies. A novel dataset was constructed allowing for the analysis of the cross-border M&A effects on the innovation and financial performance of China's publicly listed firms. We rely on matching techniques combined with a difference-in-differences approach in order to help correct for potential sample selection bias and add to the literature on China's cross-border M&A with a valuable empirical study at the firm- and patent level. Our main findings suggest that completing a cross-border M&A has both an immediate and persistent positive impact on firms' innovation efforts, e.g. R&D intensity. By contrast, we find somewhat mixed findings on the effects of cross-border M&A on firms' innovation performance, depending on both the specific proxy and aspect of innovation. Our analysis indicates immediate and sustained positive effects in the number of patent applications while we find increases in the number of granted patents after a two-year delayed period. Whereas with respect to innovation quality, cross-border M&A seem to eventually increase the number of patent claims, indicating superior post-deal innovation for merging or acquiring firms. Finally, our results suggest that cross-border M&A lead to lower financial performance in the years following the foreign M&A deal of Chinese listed firms.

A number of limitations warrant attention. Apart from the aforementioned potential issues with the empirical strategy adopted, our analysis is conducted on the limited sample of China's A-listed firms, whereas a considerable part of China's cross-border M&A is conducted by non-listed private and state-owned firms. Thus, extending the investigation to larger universes of Chinese firms would be an important field for future research. Further, our articles focuses, as our data only allows for, on the examination from the point of view of the Chinese acquirer. Another interesting extension would be to not only include the effects on the target companies but also to take into account the technological relatedness between acquirer and target company of the cross-border M&A.

## 3

# International Collaboration for a Catch-up in Innovation? The Case of Chinese Co-inventions in Europe

Looking at the issue of technological development from a pure numbers perspective, China has shown a remarkable and steep increase of commonly used research and development (R&D) input and output indicators since the early 2000s. Parallel to high growth rates in its GDP, research and development (R&D) expenditures, science and technology (S&T) personnel and research infrastructure numbers have risen at an impressive pace. On the R&D output side, patent numbers of Chinese firms have “exploded” (Hu and Jefferson, 2009; Hu, 2010).

In fact, China’s State Intellectual Patent Office (SIPO) has become the world’s largest filing office in 2014. Chinese patent application and grants have also soared in major foreign patent offices, such as the United States Patent and Trademark Office (USTPO) and the European Patent Office (EPO), as well as the World Intellectual Property Organization (WIPO), where patent protection is subject to more rigorous examination. (Kesan et al., 2016; van Dijk et al., 2015; Wunsch-Vincent et al., 2015). In Europe,

Chinese telecommunications giant Huawei has become patent application filer number one at the EPO in 2017 and a rising number of other Chinese technological firms such as Xiaomi, BYD and Tencent are increasingly filing their inventions there.

Hence, a growing number of Chinese firms seem to be increasingly capable of technological inventorship. Apart from entering mature foreign markets via trade and foreign direct investment, they show an increasing will to protect the results of their R&D efforts in these markets. A topic which has drawn increasing interest by researchers is the aspect of cross-border inventions in these growing application numbers. Indeed, cross-border collaboration for inventions has risen globally across all technology fields over the last years, with the exception of technologies related to health (OECD, 2009, 2017). International collaboration in R&D and cross-border co-inventions are no longer reserved to countries from developed economies alone, but increasingly performed by emerging economies, too (Branstetter et al., 2015; Giuliani et al., 2016; Chen et al., 2013). Given the sheer size of its economy and the continuous expansion of its domestic and international R&D activities, China arguably takes a special and leading role in these international innovation networks and cross-border co-inventions of emerging economies. However, only a very limited number of articles has investigated the pattern of Chinese collaborative R&D activities abroad and if and how cross-border co-inventions contribute to a technological catch-up of China.

This paper contributes to this literature and the understanding of China's internationalization and technological catch-up attempt. In particular, I investigate the relationship between the international co-inventing and the patent quality in Chinese patent applications. I first explore the pattern of Chinese international co-inventions in Europe as a leading R&D hub descriptively. The study then scrutinizes the role cross-border co-inventions play for the quality of Chinese overseas patent applications by comparing them with inventions which were created by purely domestic teams. For this study I rely on different patent information databases, namely EPO's

PATSTAT and OECD's Citations, Patent Quality and REGPAT databases for information on the applicant firm, assignee and inventor countries, technological classes as well as different quality indicators of the patent. My results show that Chinese cross-border co-invention has been relatively concentrated in a number of international partner countries and the share of international co-inventing in the different technology fields lies below international average. Assessing the relationship between cross-border co-invention and patent quality by the patent quality proxies of number of forward citations, number of claims and family size, I find a positive and strong association of engaging in international co-invention and patent quality.

The remainder of the paper proceeds as follows: Section two explores the economic literature on international R&D collaboration and the technological development of China related to my research question. Section three provides detailed information on the data and methodology used in the analysis. Subsequently, section four presents and discusses descriptive and econometric results. Finally, section five concludes.

## **3.1 International R&D collaboration and technological catch-up of China**

### **3.1.1 International R&D collaboration**

Collaboration in inventive activities, whether performed domestically or internationally, permits a combination of individual capacities and know-how of the different members of inventor teams and spurs creativity (March, 1991; Fleming et al., 2007). Given the preferential and mutually supportive and dependent character of networks, they are reciprocal and build on experience and trust (Powell, 1990). Geographical, cultural as well as institutional closeness facilitate trust and, in turn, the establishment of technological collaboration (Paci and Batteta, 2003; Picci, 2010).

In a study on the determinants of global networks at the country level, De Prato and Nepelski (2013b) identify the size of the economy (and hence the economic potential of a market) and inventive capacities of the partner country as measured in its patent numbers as additional specific driving forces, while geographic and cultural distance are shown to have significant moderating effects. As De Prato and Nepelski (2013a) explain in a different study, there are three main criteria determining the choice of partner and location in the internationalisation of R&D and co-inventive activities in particular: i) access to resources which are mostly non-transferable and location-specific, ii) the macroeconomic environment of the host country, and iii) the cost of performing research & development abroad. The latter holds especially for developing countries, where private as public research entities expect to find relatively low cost of the local R&D workforce and/or various forms of government incentives to engage in collaboration.

At the same time, international collaboration in R&D and cross-border co-inventions are no longer reserved to countries from developed economies alone but increasingly performed by emerging economies, too (Von Zedtwitz and Gassmann, 2016; De Prato and Nepelski, 2013b). Companies from emerging economies possess of increasing access to and increasingly engage in cross-border innovation networks (Chen et al., 2013; Nepelski and De Prato, 2014; Branstetter et al., 2015). Cross-border co-inventions therefore are seen as a potential means for emerging economies to transfer knowledge from technological leading economies to emerging economies (Montobbio and Sterzi, 2013, 2011; Giuliani et al., 2016).

### **3.1.2 International Chinese patents, technological catch-up and patent quality**

Given the sheer size of its economy and recent numbers development explained above, China arguably takes a special and leading role in these cross-border innovation networks and cross-border co-inventions of emerg-

ing economies.

Clearly, China's international co-inventions are on the rise as different studies have shown (Branstetter et al., 2015; OECD, 2009; van Dijk et al., 2015). However, with regards to a potential effect of cross-border co-inventions on the quality of Chinese patent applications, no general statement can be made about the quality of cross-border co-inventions compared to the quality of domestic inventions.

Generally, on the one hand, it is argued that patents that stem from collaboration are more valuable than individual patenting, due to the combination of various knowledge and capability sources within teams, which integrate diverse competences and spur creativity (March, 1991; Fleming et al., 2007). On the other hand, the positive net effect is however challenged by other studies which emphasize the high coordination and integration costs of combining knowledge in cross-border co-inventorship and R&D (Singh, 2008), promoting local over global knowledge production (Furman et al., 2006).

The relationship between the international co-invention activities and the patent "quality" of these patents are the focus of interest in the following sections of analysis.

While there has been ample discussion in the literature on the concept of patent quality and how to assess it<sup>1</sup>, the economic literature proposes various proxies for its measurement. The most typical patent quality metrics in economic studies include (Squicciarini et al., 2013a; Prud'homme, 2017): i) Patent renewal: Once granted, patents of higher value to the holder are expected and were shown to be renewed more often, given the occurring costs at each renewal (Pakes, 1986; Lanjouw et al., 1998), ii) Forward Citations: The number of received citations by other patent filings are an indication of the impact, technological importance for subsequent

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<sup>1</sup>There are differing viewpoints on the concept of patent quality, also depending on whether the legal perspective or the technological value perspective is taken. The listed metrics above are therefore not exhaustive but were reviewed for the purpose of this study

technologies and implied economic value of an invention (Trajtenberg, 1990; Hall et al., 2005; Harhoff et al., 2003), iii) Family size: The number of jurisdictions that the patent application is filed at (= family size) implies, generally, increasing costs per additional jurisdiction and extension of markets that the invention can be commercially exploited (Grupp and Schmoch, 1999; Lanjouw et al., 1998). A large family size of patents has been shown to be of particular economic value to its holders ((Harhoff et al., 2003), iv) Breadth of the patent application: Corresponding to the number of technological sub-classes<sup>2</sup> that the invention is allocated to, the breadth or scope of a patent could indicate its potential technological impact, v) The number of claims: A larger number of claims may not only correspond to the technological breadth of the patent but also to the breadth of the rights conferred to its holder and occurring fees for the holder with an increasing number of claims. More claims can hence indicate a higher expected market value (Lanjouw, 2001; Tong and Davidson Frame, 1994). However, it can also be argued that patents of lower quality might potentially be substantiated by including more claims in the application, a potential shortcoming that one needs to be aware of when using claims as an indicator for patent quality.

The main question that this study aims to help answer is if co-inventing internationally adds value to Chinese patent applications and hence whether it leads to an increase in the inventive capacities of Chinese entities.

## **3.2 Data and Methodology**

### **3.2.1 Chinese overseas patent data and patent quality indicators data**

For the purpose of the study of Chinese overseas applications in Europe and the link between cross-border co-invention and patent quality, I construct

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<sup>2</sup>Sub-classes here are considered at the 4-digit International Patent Classification level

a dataset based on specific data extractions from three different databases. I extract and merge patent information data from

- i) PATSTAT, the Worldwide Patent Statistical Database of the European Patent Office,
- ii) OECD Patent Quality Database and
- iii) OECD Citations Database.

From i) PATSTAT, I retain detailed patent information of all published Chinese patent applications between 2000 and 2016 (PATSTAT version fall 2016) at the EPO, which are either Euro-Direct or Euro-Patent Convention Treaty (Euro-PCT) patent applications filed by an entity residing in China (Mainland China, Hong Kong and Macao). The "resident criterion" is commonly used in economic patent studies. Euro-Direct patent applications are filed directly at the European Patent Office for patent protection in all or a number of European jurisdictions. Euro-PCT patents are international patent application at the World Intellectual Property Office with the EPO as receiving office and the optional posterior choice of the applicant to enter into the European phase. Euro-PCT patent applications can take up to 30 months until publication and, given the truncation of the data from 2013 onwards for this reason, I restrict my analysis to Chinese patent applications between the years 2000 and 2014. The starting year 2000 is chosen because there are less than 10 co-inventions before 2000 and the start of the new millennium also marked the start of increased internationalization of Chinese firms, following the larger concept of the Chinese government's "Going Out" strategy, encouraging firms to reach for overseas markets.

The patent application sample contains name, address and resident country information on applicant(s) and inventor(s) and other relevant information like grant status, family size (number of jurisdictions the application has filed protection for) and its International Patent Classification (IPC) class-code(s) as well as the related technology classes these IPC code(s)

fall into. The concordance allows to classify the patent into a primary (WIPO) technology area and technology field(s) the application belongs to.<sup>3 4</sup>

To this set of Chinese patent applications as defined, I merge further variables from the OECD Patent Quality Database (OECD, 2018) and the OECD Citations Database (OECD, 2018), both based on PATSTAT fall 2017 version. The OECD Patent Quality Database contains information on the scope of the patent, patent family size, grant lag and ready-to-use indices on generality, originality, and radicalness of the patent as well as indices with combinations of the individual indicators mentioned. From the OECD Citations Database I merge several variables with information on the citations of the respective patent, namely the number of all patent citations made (backward citations), the number of references to non-patent literature (NPL) and the number of total citations received within 5 years as either European Patent (EP) or World Intellectual Property Organization publication (WO) (forward citations).<sup>5</sup>The resulting final sample consists of 25,603 patent applications by a Chinese resident entity signing as first applicant and with i) a purely domestic inventor team (total: 24,754) or ii) at least one domestic Chinese co-inventor and at least

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<sup>3</sup>WIPO distinguishes between five broad technology sectors/classes:

(1) Electrical engineering, (2) Instruments, (3) Mechanical Engineering, (4) Chemistry, and (5) Other fields.

These five sectors are further broken down into 35 technology fields:

(1) - Electrical machinery, apparatus, energy; Audio-visual technology; Telecommunications; Digital communication; Basic communication processes; Computer technology; IT methods for management; Semiconductors ;

(2) - Optics ; Measurement; Analysis of biological materials; Control; Medical technology;

(3) - Organic fine chemistry; Biotechnology; Pharmaceuticals ; Macromolecular chemistry, polymers; Food chemistry; Basic materials chemistry; Materials; Metallurgy; Surface technology, coating; Micro-structural and nano-technology; Chemical engineering; Environmental technology;

(4) - Handling; Machine tools; Engines, pumps, turbines; Textile and paper machines; Other special machines; Thermal processes and apparatus; Mechanical elements; Transport;

(5) - Furniture, games; Other consumer goods; Civil engineering

<sup>4</sup>In case of several class codes, I use the first code given and follow the WIPO technology sector and field classification of (Schmoch, 2008)

<sup>5</sup>See <http://www.oecd.org/sti/inno/oecdpatentdatabases.htm> and (Webb et al., 2005) for more detailed information on the OECD Patent Quality and Citations databases

one international co-inventor (total: 849). The total number of unique applicants in the final sample is 5,237.

### **3.2.2 Methodology**

Along the explanations in above, I use three separate indicators commonly used in the economic literature to assess patent quality, namely the number of forward citations, the number of claims and the family size of the patent application.

*Forward citations* of a patent are known and have been shown to be a strong and commonly used indicator for patent value in the pertinent literature (Squicciarini et al., 2013a; Trajtenberg, 1990; Hall et al., 2005).

*Claims* measure the number of claims that the patent assignee(s) indicates in their patent application and relates to the scope and breadth of the invention that they want to protect, the costs and therefore the value it might have (Lanjouw and Schankerman, 2004; Lanjouw, 2001; Tong and Davidson Frame, 1994).

*Family size* is an indicator which counts the number of jurisdictions that the patent is filed in. A higher number of jurisdictions that the patent is filed at is associated with a higher value of the patent (Grupp and Schmoch, 1999; Lanjouw et al., 1998). As describe above, patent renewal is another important and valid proxy for an assessment of patent quality. However, patent information on the number of renewals is (naturally) built on patents which were granted and inclusion into an analysis requires a certain and relatively long delay of observations. Focusing on patent applications and interested in a relatively recent phenomenon and data, the indicator on renewal cannot be included in the analysis and I focus my subsequent analysis on the chosen three quality indicators.

I choose to estimate the effect of cross-border invention on the quality of the patent applications via Poisson Quasi Maximum Likelihood estimation (PQML). The choice of this estimator has several reasons. Firstly, all of

the three outcome variables to be tested are non negative integers and a count data model is therefore suitable. Secondly, PQML allows for the overdispersion present in the data. Lastly, my choice follows the pertinent literature in the subject of interest as the most related studies to this study opted for a similar estimation technique for the same reasons explained (Branstetter et al., 2015; Giuliani et al., 2016; Alnuaimi et al., 2012).

In a PQML estimation, the expected value is modelled via an exponential function (Wooldridge, 2003, pp. 573-578):

$$E(y|x_1, x_2, \dots, x_k) = \exp(\beta_0 + \beta_1x_1 + \dots + \beta_kx_k) \quad (3.1)$$

Taking the log of equation (3.1) and adapting the general model to my specification, my model takes the following form

$$\begin{aligned} \log[E(\text{Patent Quality}|X)_{i,t}] = & \beta_0 + \beta_1\text{IntCoinv}_{i,t} + \beta_2\text{Teamsize}_{i,t} \\ & + \beta_3\text{BwdCits}_{i,t} + \beta_4\text{NonPatentLitCits}_{i,t} \\ & + \beta_5\text{IntCoinvExperience}_{i,t-1} + \beta_6\text{YearFE}_t \\ & + \beta_7\text{TechFieldFE}_i + \varepsilon_{i,t} \end{aligned} \quad (3.2)$$

with the logarithm of the expected value in linear form.

*PatentQuality* is the number of the respective measure of patent quality of the Chinese patent application  $i$  in year  $t$ , namely the number of Forward Citations, the Number of Claims and the Family Size of the patent application.<sup>6</sup>

The main (explanatory) variable of interest is *IntCoinv* <sub>$i,t$</sub>  and its coefficient, the key coefficient to interpret. It is a binary variable which takes the value 1 if the Chinese patent application has been co-invented by

<sup>6</sup>The priority year marks the year in which a patent application was first filed to any patent jurisdiction. In this study, the year of an patent application relates to the priority year of the patent application for this and all other variables used in this study. Priority year and filing year of a patent application might differ if the same patent had already been filed at a different patent office and was extended to the EPO at a later point.

at least one Chinese co-inventor and at least one non-Chinese/foreign co-inventor and takes the value 0 if the inventor team has consisted of purely domestic inventors for patent application  $i$  in year  $t$ . The model allows for a calculation of the proportionate change in the expected value by taking the exponential of the estimated value of  $\beta_1$  in equation (3.2),  $\hat{\beta}_1$ , and subtracting it by 1. For the interpretation of the percentage change in the regression's result this estimated value needs to be multiplied by 100.

The control variables include a range of factors that may influence the quality of the patent application, namely *Teamsize*, *BwdCits*, *NonPatentLits* and *IntCoinvExperience*.  $Teamsize_{i,t}$  is the number of inventors responsible for the patent application  $i$  in year  $t$ . Larger teams are generally expected to produce more valuable inventions (Wuchty et al., 2007).  $BwdCits_{i,t}$  designates backward citations made in application  $i$  in year  $t$ . As shown by previous literature, backward citations were found to point at a higher value of patent (Harhoff et al., 2003; Squicciarini et al., 2013a).  $NonPatentLitCits_{i,t}$  represents the number of citations of the respective patent in non patent related literature. Larger number of citations points at a larger impact, hence a higher value of the patent (Squicciarini et al., 2013a).  $IntCoinvExperience_{i,t-1}$  indicates the stock of international inventions that the Chinese applicant filing has developed before the priority year in which the patent was filed. Including this "experience" variable at the assignee/firm level controls for the potential effect that differing prior experience of the assignee/firm in international co-invention might have on the value and characteristics of the patent application (Phene and Almeida, 2003). All those four control variables enter the regressions that estimate equation (2) in their logarithmic form. Further, I include a set of fixed effects at the year and technology level (WIPO 35 technology field level) accounting for variation in the outcome that happens over time and across technologies that cannot be attributed to the other explanatory variables.  $\epsilon_{i,t}$  is the error term.

## 3.3 Results

### 3.3.1 Descriptive Results

First, I present descriptive results which were found during the analysis. Figure 1 illustrates the worldwide distribution of international co-inventors in Chinese patent applications at the EPO during the period 2000 to 2014<sup>7</sup>. The global distribution of international (co-)inventors of Chinese patent applications in Europe is illustrated in fractional counts<sup>8</sup>. The US clearly dominates with a total of 200 between 2000 and 2014<sup>9</sup>, while all of the EU-28 Member States group together a total of 73 co-inventions in fractional counts. Other major important contributors partnering countries are Taiwan (36), Canada (27), Japan (10), Australia (10) and Switzerland (6).

Other Asian neighbouring countries of China apart from Taiwan only play a very minor role in China's co-inventing activities as seen through Chinese applications at the EPO: Singapore (3), India (3), Korea (1) and Russia (1) all show a small propensity to co-invent with Chinese inventors for Chinese filings in Europe<sup>10</sup>.

A more detailed picture for the EU-28 Member States is presented in Figure 2 which depicts the distribution of European international co-inventors in Chinese patent applications at the EPO during the period 2000 to 2014<sup>11</sup>: Inventor teams in Germany are the leading co-inventing group with a total fractional count of 21. The other major European co-invention localizations are France (13), the UK (10), Sweden (10) and Italy (8).

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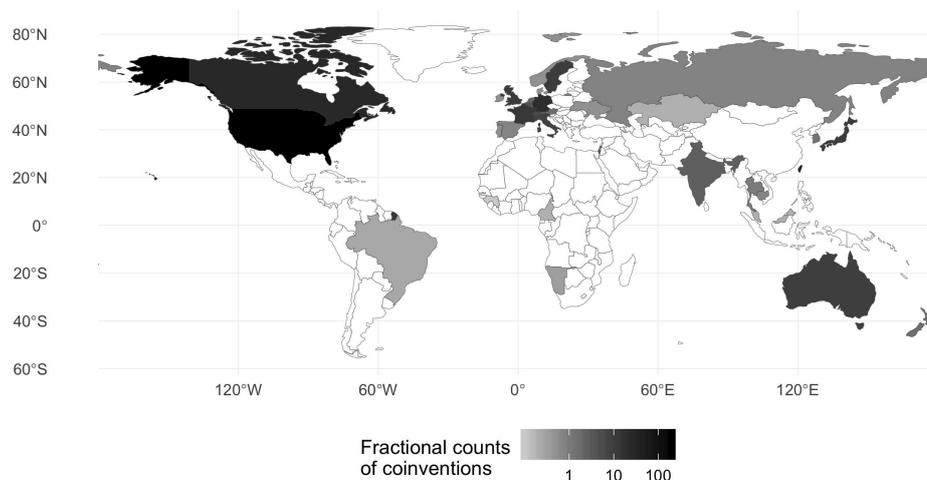
<sup>7</sup>Patent data truncation starting in 2013

<sup>8</sup>Fractional counts count the contribution of co-inventors to a individual patent application. The share is allocated to each inventor/her country, which allows the fractions to be summed without double counting. Fractional count are additive at all scales, permitting a calculation of the total a correct comparison between countries.

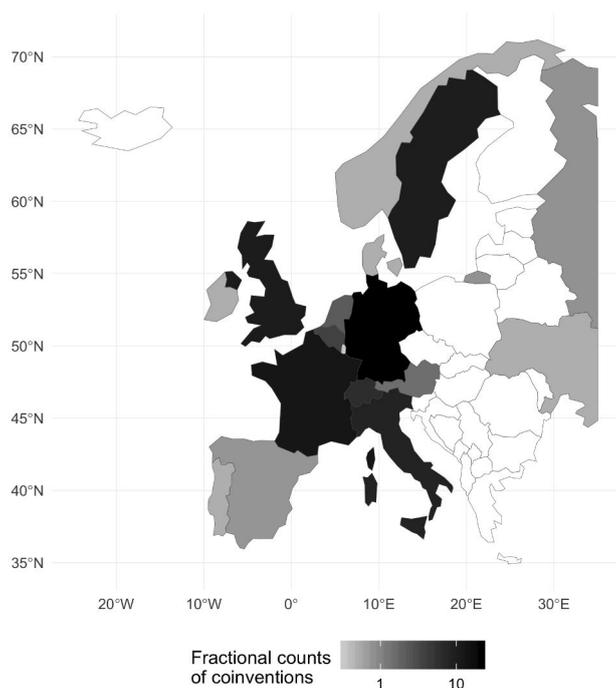
<sup>9</sup>Patent data truncation starting in 2013

<sup>10</sup>When taken separately from Mainland China, Hong Kong has a fractional count of 15 co-inventions in Chinese applications at the EPO between 2000 and 2014

<sup>11</sup>Patent data truncation starting in 2013



**Figure 3.1:** Worldwide distribution of international co-inventors in Chinese patent applications at the EPO (2000-2014)



**Figure 3.2:** Regional distribution of international co-inventors in Chinese patent applications at the EPO (2000-2014)

As for the main global co-invention partner countries, these figures are strong indicators for where Chinese firms allocate their overseas R&D activities and to which countries China maintains the strongest scientific and industrial ties.

Next, it is insightful to inspect the technological split of Chinese applications and their share of cross-border inventions. Table 1 below presents the distribution of Chinese patent applications between the years 2000 and 2014 at the EPO by technology field<sup>12</sup>. Further the table lists the amount of applications which were the product on co-inventions between Chinese and international co-inventors, the respective share in the total counts and ranks the technology classes accordingly. The technology classes to which Chinese patent applications in Europe are attributed to exhibit a strong heterogeneity in their international co-invention share: *Machine tools* lead the list with 15% and several fields of the technology area chemistry for example, such as *Organic fine chemistry* (8%), *Biotechnology* (7%), *Pharmaceuticals* (7%) and *Chemical engineering* (6%) show a relatively high degree of international participation in the invention process. The top fields in terms of total applications in our defined sample, such as *Digital communication* (Total counts: 8,235; international share: 2%), *Telecommunication* (Total counts: 2,496; international share: 3%), *Computer technology* (Total counts: 2,122; international share: 3%) and *Electrical machinery, apparatus, energy* (Total counts: 1,436; international share: 2%), all belonging to the Electrical Engineering technological area, show a comparatively low international co-invention share.

Before running the regressions of the model developed above, I explore the data further and perform a t-test for the differences of the different patent quality indicators between inventions that feature purely domestic productions versus inventions featuring at least one international inventor. Table 2 below compares the descriptive statistics and lists the results for the chosen patent quality indicators in the two groups sample t-test. It is performed for three chosen patent quality indicators, (1) the number of forward citations (within a 5 years citation window), (2) the number of claims in the Chinese patent application, and (3) the size of the family of the patent application for the period 2000 to 2010. This time window is chosen because of the indicator of forward citations, which, in order to be

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<sup>12</sup>Patent data truncation starting in 2013. Technology classification following the WIPO technology fields developed in Schmoch (2008)

WIPO Technology Field	Count	International co-inventions	Share
Machine tools	332	49	14.76
Thermal processes and apparatus	280	23	8.21
Organic fine chemistry	792	60	7.58
Other special machines	275	20	7.27
Biotechnology	479	34	7.10
Pharmaceuticals	818	56	6.85
Surface technology, coating	164	11	6.71
Chemical engineering	328	21	6.40
Food chemistry	80	5	6.25
Semiconductors	394	21	5.33
Macromolecular chemistry, polymers	226	12	5.31
Measurement	589	28	4.75
Basic materials chemistry	319	15	4.70
Audio-visual technology	967	38	3.93
Furniture, games	638	24	3.76
Engines, pumps, turbines	273	10	3.66
Micro-structural and nano-technology	29	1	3.45
Medical technology	611	21	3.44
Textile and paper machines	215	7	3.26
Computer technology	2122	61	2.87
Basic communication processes	213	6	2.82
Telecommunications	2496	70	2.80
Transport	509	14	2.75
Civil engineering	339	9	2.65
Electrical machinery, apparatus, energy	1436	38	2.65
Handling	243	6	2.47
Other consumer goods	474	11	2.32
Optics	530	11	2.08
Control	199	4	2.01
Environmental technology	159	3	1.89
Mechanical elements	225	4	1.78
Materials, metallurgy	394	7	1.78
Digital communication	8235	146	1.77
IT methods for management	220	3	1.36
Total	25603	849	3.32

**Table 3.1:** Chinese applications with Chinese inventor or (co-)inventor at EPO - Total count and international co-inventions by technology field (2000-2014)

not truncated and fully interpretable, must include a certain time window. The most common time window in the pertinent literature is five years, which is also applied in this study.

The t-tests reveal that the means of the number of forward citations (in a five years window), the number of claims and the family size of the patent applications of these two groups are significantly different. Generally, international co-invented patent applications have more forward citations (0.65 vs. 0.49 forward citations), more number of claims (16.7 vs. 13.4 claims) and are of a larger average patent family sizes (5.2 vs. 4.4 in family size) than solely domestically invented ones. The statistical difference holds for the sample containing more recent application from 2000 to 2014 (including number of claims and family size). The means for the number of claims and family size are comparably equal for the full sample until 2014.

### **3.3.2 Regression results**

This sub-section examines the results of the regressions of the effect of international co-invention on patent quality, as measured through the different patent quality indicators. Table 2 first presents the effect on (1) the number of forward citations (within a 5 years citation window), (2) the number of claims in the Chinese patent application, and (3) the size of the family of the patent application for the period 2000 to 2010. The indicator of forward citations must include a certain time window, in order to be not truncated and fully interpretable. The most common time window in the pertinent literature is five years, which is also applied in this study. All estimations are performed with a PQML estimator and robust standard errors. In table 2, for all three patent quality indicators, results are first shown without controls chosen (left column), then including the controls (right column). All regressions include fixed effects for years and technology fields at the WIPO 35 technology level, in order to account for year and technology specific heterogeneity which is not captured by other

Sample 2000-2010 (n=14,850)									
	Domestic Inventions (n= 14,348)		International co-inventions (n=502)						
	Mean	Std. deviation	Mean	Std. deviation					
Forward Citations	0.4871 (0.0085205)	1.0206	0.649 (0.0554142)	1.2415					
Number of claims	13.3659 (0.0519805)	6.226387	16.7173 (0.4175831)	9.356099					
Family size	4.377405 (0.0195774)	2.345042	5.249004 (0.157387)	3.526312					
					Eq. variances assumed	Difference	t-statistic	p-value	
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
Sample 2000-2014 (n=25,603)									
	Domestic inventions (n= 24,754)		International co-inventions (n=849)						
	Mean	Std. deviation	Mean	Std. deviation					
Number of claims	13.34605 (0.0359753)	5.660145	16.09658 (0.2787019)	8.120705					
Family size	4.221904 (0.0138749)	2.182999	4.964664 (0.110614)	2.229174					
					Eq. variances assumed	Difference	t-statistic	p-value	
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				
					Eq. variances assumed				
					Eq. variances not assumed				

**Table 3.2:** t-Test on differences in patent quality indicators between international co-invented and domestic Chinese patent application at the EPO, 2000-2010 and 2000-2014

Dependent Variable	(1)		(2)		(3)	
	Forward Citations		Number of Claims		Family Size	
Int Coinv	0.330*** (0.0862)	0.269** (0.0850)	0.239*** (0.0248)	0.208*** (0.0253)	0.0956*** (0.0282)	0.0988*** (0.0283)
Log Teamsize		0.184*** (0.0255)		0.0589*** (0.00635)		0.0328*** (0.00658)
Log Bwd Cits		0.178*** (0.0400)		0.0170 (0.00901)		0.0756*** (0.00969)
Log NPL Cits		0.226*** (0.0268)		0.0323*** (0.00604)		0.0259*** (0.00677)
Log Int CoInv Experience		0.0404* (0.0189)		0.0429*** (0.00382)		-0.0252*** (0.00367)
Year dummies	YES	YES	YES	YES	YES	YES
Technology field dummies	YES	YES	YES	YES	YES	YES
_cons	-0.519 (0.403)	-1.196** (0.430)	2.665*** (0.0745)	2.589*** (0.0761)	1.911*** (0.0853)	1.743*** (0.0871)
<i>N</i>	14850	14850	14850	14850	14850	14850

Robust standard errors in parentheses

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

Note: Forward citations consider forward citations in a five year window.

**Table 3.3:** Poisson quasi maximum likelihood estimation of effect of international co-invention on patent quality indicators of Chinese patent applications at the EPO (2000-2010)

explanatory variables.

My results show that international co-invention has a positive and strong association with patent quality for Chinese patent applications in Europe. I find that Chinese patent applications that feature at least one international co-inventor are expected to have more forward citations, number of claims and a larger family size of the patent than patents which were invented by domestic inventor teams in China. The size of the association differs by the different measures of patent quality chosen in this study: For forward citations, international co-inventing is associated with an expected increase of forward citations by 31%<sup>13</sup> while the number of claims are expected to increase by 23%. As for the family size of the patent application, the results show an expected 10% quality premium.

<sup>13</sup>calculated by  $(\exp(0.243)-1)*100$

Dependent Variable	(1) Number of Claims	(2) Family Size		
Int Coinv	0.201*** (0.0171)	0.167*** (0.0175)	0.102*** (0.0208)	0.113*** (0.0210)
Log Teamsize		0.0512*** (0.00437)		0.0248*** (0.00492)
Log Bwd Cits		0.0205** (0.00638)		0.0542*** (0.00710)
Log NPL Cits		0.0331*** (0.00434)		0.0170** (0.00525)
Log Int Coinv Experience		0.0301*** (0.00188)		-0.0268*** (0.00197)
Year dummies	YES	YES	YES	YES
Technology field dummies	YES	YES	YES	YES
_cons	2.642*** (0.0624)	2.563*** (0.0614)	1.724*** (0.0710)	1.609*** (0.0725)
<i>N</i>	25603	25603	25603	25603

Robust standard errors in parentheses

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

**Table 3.4:** Poisson quasi maximum likelihood estimation of effect of international co-invention on patent quality indicators of Chinese patent applications at the EPO (2000-2014)

Next, I proceed to the regression analysis for the patent quality indicators of number of claims and family size in Table 4, for the full sample from 2000 to 2014. Again, for both patent quality indicators, results are first shown without controls chosen (left column), then including the controls (right column). All regressions include fixed effects for years and technology fields at the WIPO 35 technology level, in order to account for year and technology specific heterogeneity which is not captured by other explanatory variables.

Here my results confirm, over the entire period observed, that international co-invention has a positive and strong association with patent quality for Chinese patent applications in Europe as seen through the lens of the

number of claims and the family size of the applications. The coefficients for international invention are slightly higher than in the 2010 sample and suggest that, compared to purely domestic inventions, the number of claims are expected to increase by 18%<sup>14</sup> while an expected 12% quality premium is suggested for the family size of the invention.

### **3.4 Conclusion**

International collaboration in R&D and cross-border co-inventions are no longer reserved to countries from developed economies alone, but increasingly performed by emerging economies. China plays a special role in these developments and this article contributes to bring new insights to this topic of increasing importance. It is shown descriptively that China's international co-inventive activity in patent applications in Europe is concentrated in terms of technologies and partner countries. Econometric results found in this article demonstrate that international co-invention activity of Chinese firms is associated with an increasing patent quality of Chinese patent applications at the EPO. Chinese patent applications which involve international co-inventors during its creation process are found to feature more forward citations, a higher number of claims and a larger family size of patents as compared to domestic patents developed in China.

These results align with the results found in the literature examining the effects of international co-invention on the quality of patents, through the lens of other samples in advanced and emerging economies, i.e. Alnuaimi et al. (2012) for the US semiconductor industry, Branstetter et al. (2015) for Indian and Chinese multinational enterprises and their patenting at the United States Patent and Trademark Office, and Giuliani et al. (2016) for the pool of Brazilian, Chinese and Indian multinational enterprises and their co-inventions with European partners in Europe.

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<sup>14</sup>calculated by  $(\exp(0.167)-1)*100$

With this study come some limitations, too. I acknowledge that the chosen methodology could not avoid potential reverse causality of the relationship between international co-invention and the quality of patents. That is, more promising and valuable invention projects are potentially allocated to international teams and not randomly assigned to either international or domestic teams. Suitable instrumental variables and two stage regressions might help to overcome this constraint and are an important subject for future research.

# Conclusion

The subject of this doctoral thesis revolves around the analysis of China's policies, foreign direct investment, and international collaboration with regard to innovation.

Chapter one, co-written with Ilja Rudyk, explores the rise of Chinese inventions in Europe, China's innovation policies, and assesses their effect with regard to domestic ownership in strategic technologies through the lens of European patent data. Chapter two, joint work with Anthony Howell and Jia Lin, investigates the effects of Chinese cross-border mergers and acquisitions on the domestic innovation activities and financial performance of the firms engaging in such foreign direct investment. The third chapter addresses the relationship between international collaboration and patent quality through an analysis of Chinese patent applications in Europe.

In chapter one, we first look at the sharp increase of Chinese inventions and co-inventions in Europe and then explore China's innovation policies with a particular focus on one of their major goals. As we demonstrate, developing independent innovative abilities and reducing the dependency on foreign technology lays at the core of China's innovation policy plans. Two cornerstones and directives of this overarching objective are China's National Medium and Long-Term Program for Science and Technology Development (MLP) and the 12th Five-Year National Development Plan of Strategic Emerging Industries (SEI) promulgated by the State Council in 2006 and 2012 respectively. As one of their shared major goals, they aim at developing an increased ownership of Intellectual Property Rights (IPRs)

in targeted strategic technology classes that the Chinese government considers key for the future development of its country. Chapter one analyzes the potential effect of the (indigenous) innovation policies on China's overseas inventions with European patent data. To this end, we construct a concordance table of the detailed targeted technology classes in the policy plans and their corresponding international patent classification (IPC). Subsequently, we employ the difference-in-differences method to test whether China increasingly owns its indigenous inventions in the targeted technology fields by looking at developments in Chinese as opposed to foreign "ownership" of patents which involve Chinese inventors. Our results suggest that the two major policies have been successful in generating a higher ownership share in the targeted technologies after their implementation. Further, we are interested in the question if there has been a detrimental effect of the policies on the characteristics of the inventions filed in the specifically targeted fields. Here we find differing results for the two plans and depending on the indicator used. While the introduction of the MLP policies is found to have led to less claims, there is no indication of a significant change for forward citations and family size in the targeted classes. For the SEI, our results point at a positive effect on impact and quality of the targeted classes.

Chapter two explores the effects of Chinese firms' cross-border M&A on the subsequent domestic innovation and financial performance of Chinese listed companies. It employs matching techniques combined with a difference-in-differences estimator to investigate the causal effects of cross-border M&A on firms' investments in innovation, innovation outputs, and financial performance. To this end, we constructed a unique firm-level data set, linking the general business and financial information for all companies listed at China's A-share stock exchange markets at Shanghai and Shenzhen with all cross-border, majority M&A deals of these firms. We further add the domestic patent portfolios of the firms to the dataset, using public patent information of the State Intellectual Property Office of China (SIPO). We show that engaging in cross-border M&A has a strong and positive association with a rise in post-deal R&D intensity of the firm

investing as well as with a rise of the patent applications and grants in the years following the investment. We find the same positive relationship for patent quantity as proxied by the number of claims in the patent applications. With regard to post-deal financial performance our results, however, indicate a negative association.

Finally, in chapter three I take a closer look at the role engaging in international collaboration. In particular, I study the relationship between international co-invention and the quality of patents filed by Chinese entities in Europe. For this study, I rely on different patent databases, including EPO's PATSTAT and OECD's Citations, Patent Quality and REGPAT databases. I first analyzed the pattern of Chinese international co-inventions in Europe as a leading R&D hub and then investigate the role cross-border co-inventions play for the quality of Chinese overseas patent applications as measured in different patent characteristics. I show that cross-border co-inventions-Chinese cross-border co-inventions are relatively concentrated in a number of international partner. My empirical results suggest that international co-invention activity is associated with a strong increase in patent quality for Chinese patent applications at the EPO. Chinese patent applications which involve international co-inventors during the creation process are found to feature more forward citations, a higher number of claims and a larger family size as compared to domestic patents developed in China.

Each of these chapters contributes to the literature along multiple lines. Chapter one contributes to the literature on innovation policies in emerging economies and the understanding of China's technological development and catch-up attempt in particular. We construct a concordance table for the two major indigenous innovation policies of China at the 4-digit international patent classification (IPC) level via the IPC-classification tool of the World Intellectual Property Organization. Further, we provide an empirical assessment of China's indigenous innovation policy with regard to targeted domestic ownership and potential effects of the measures on patent quality. Chapter two contributes to the literature on the techno-

logical upgrading of emerging economies and particularly China through foreign direct investment. A unique dataset was built at the firm-level and suited for analysis at the patent level. We combine all cross-border M&A deals of listed companies in Shanghai and Shenzhen since the start of the millennium with their balance sheet information and merge their domestic patent portfolio at China's intellectual property office. Further, we differ from and extrapolate existing studies in the literature by considering and assessing the impact of China's cross-border M&A not only on R&D intensity and patent quantity but also patent characteristics that reflect their quality. The analysis in chapter three contributes with new insights to the topic of international collaboration in invention as a means of technological upgrading for emerging economies. I illustrate the concentration of partner countries and technology classes in which Chinese inventors team up with international inventors. Further, the link between these international collaborations and patent quality is assessed empirically for Chinese patent applications in Europe.

The three chapters of the dissertation collectively aim at contributing to the understanding of China's development in innovation, its internationalization, its engagement with partner countries and the mutual risks and benefits from these processes. Having scrutinized the research questions posed in this thesis, new ones emerge from the analysis. For instance, given the controversial debate on Chinese foreign direct investments in Europe and around the world, the consequences in terms of innovative and economic output on the *target firms* seems to be of high interest to policy makers and firm managements alike. As for findings on the positive association between international collaboration and invention quality for Chinese entities, another emerging, more general topic regards the way to best engage with China's rise to innovation in the future.

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## **Appendix A**

# **The Rise of Chinese “Indigenous” Inventions: Evidence from European Patent Data**

Field/Industry	Subfield/technologies targeted
<b>Biotechnology</b>	Target identification technology; Plant-animal varieties and drug molecular design technology; Gene manipulation and protein engineering technology; Stem cell based human tissue engineering technology; Next-generation Industrial biotechnology
<b>Information technology</b>	Intelligent sensing technology; Ad hoc network technology; Virtual reality technology
<b>Advanced Materials Technology</b>	Intelligent materials and structural technology; High-temperature superconducting technology; Efficient energy material technology
<b>Advanced Manufacturing Technology</b>	Extreme manufacturing technology; Intelligent service robotics; Service life prediction technology for major products and facilities
<b>Advanced Energy Technology</b>	Hydrogen and fuel cell technology; Distributive energy supply technology; Fast neutron reactor technology; Magnetic contained fusion technology
<b>Marine Technology</b>	3-D marine environment monitoring technology; Ocean floor based multi-parameter fast sounding technology; Natural gas hydrate exploitation technology; Deep-sea operation technology
<b>Laser Technology</b>	Not specified in published document/MLP
<b>Aerospace</b>	Not specified in published document/MLP

**Table A.1:** Strategic technology fields and subfields in the MLP 2006. Source: (The State Council 2006)

Field/Industry	Subfield/technology targeted
<b>Energy conservation and environmental protection</b>	Energy efficiency; Advanced environmental protection; Resource recycling
<b>Next generation IT</b>	Next-generation information network; Core foundation electronics; Emerging high-end software and information services
<b>Bio-industry</b>	Bio-pharmaceuticals; Biomedical engineering; Biological agriculture; Bio-manufacturing
<b>High-end equipment manufacturing</b>	Aviation equipment; Satellite and industrial applications; Rail transportation equipment; Marine engineering equipment; Intelligent manufacturing equipment
<b>New energy</b>	Nuclear technology; Wind energy; Solar energy; Biomass energy
<b>New materials</b>	New functional materials; Advanced structural materials; High-performance composite materials
<b>New energy automotives</b>	New energy vehicles; power batteries; charging technology

**Table A.2:** Strategic technology fields and subfields in the SEI 2012. Source: (Prud’homme 2015; The State Council 2012)

Variable	Mean	Std. Dev.	Min.	Max.	N
Chinese Ownership	0.702	0.457	0	1	43579
Patent App in MLP time / > =2006 (MLPtime)	0.875	0.331	0	1	43579
Patent App IPC4 of MLP (MLPStrategicIPC)	0.584	0.493	0	1	43579
Interaction MLPtime & MLPStrategicIPC	0.52	0.5	0	1	43579
Patent App in SEItime/ > =2012 (SEItime)	0.371	0.483	0	1	43579
Patent App IPC4 of SEI (SEIStrategicIPC)	0.53	0.499	0	1	43579
Interaction SEItime & SEIStrategicIPC	0.213	0.409	0	1	43579
Euro-PCT application (europct)	0.828	0.378	0	1	43579
Chinese inventorship solely (cn_invent_only)	0.807	0.395	0	1	43579
Competition index in patent app's IPC4 class (IPC4_C4)	0.215	0.099	0.032	1	43579
WIPO technology field	10.707	9.890	1	35	43579
Number of forward citations (5 years window)	0.357	1.082	0	51	37203
Number backward citations	6.107	6.581	0	493	37203
Number of Claims	14.114	6.513	1	137	43579
Number of patent offices (Family Size)	4.511	2.706	1	39	37203

Table A.3: Summary statistics

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Chinese Ownership	1.000													
2 Patent App in MLP time/ > =2006 (MLPtime)	0.122	1.000												
3 Patent App IPC4 of MLP (MLPstrategicIPC)	0.103	0.102	1.000											
4 Interaction MLPtime & MLPstrategicIPC	0.140	0.437	0.861	1.000										
5 Patent App in SEItime/ > =2012 (SEItime)	0.091	0.331	0.035	0.147	1.000									
6 Patent App IPC4 of SEI (SEIstrategicIPC)	-0.018	0.127	0.371	0.354	0.076	1.000								
7 Interaction SEItime & SEIstrategicIPC	0.063	0.224	0.196	0.270	0.653	0.490	1.000							
8 Euro-PCT application	0.066	0.160	0.215	0.225	-0.006	0.171	0.070	1.000						
9 Chinese inventorship solely (cn_invent_only)	0.626	0.094	0.071	0.104	0.078	-0.036	0.040	0.007	1.000					
10 Competition index in patent app's IPC4 class (IPC4.C4)	0.012	0.161	-0.074	0.018	0.167	-0.093	0.030	0.018	0.069	1.000				
11 Forward citations (5 years window)	-0.104	-0.130	-0.007	-0.064	-0.158	-0.006	-0.113	-0.014	-0.123	-0.009	1.000			
12 Number o Backward Citations	0.026	0.067	-0.045	-0.015	-0.007	0.008	0.002	0.150	-0.017	-0.020	0.049	1.000		
13 Number of Claims	-0.150	-0.158	0.113	0.020	-0.040	0.083	0.015	0.038	-0.167	-0.043	0.122	0.000	1.000	
14 Number of patent offices (Family Size)	-0.203	-0.197	-0.038	-0.111	-0.102	0.029	-0.052	0.089	-0.240	-0.132	0.159	0.062	0.145	1.000

Table A.4: Cross-correlation table

**Table A.5:** Concordance table MLP - IPC4. Source: Authors (Keywords), MLP (Field, subfield, Full text), WIPO website (Explanation IPC4)([http://www.wipo.int/ipc/itos4ipc/ITSupport\\_and\\_download\\_area/](http://www.wipo.int/ipc/itos4ipc/ITSupport_and_download_area/))

Field/industries targeted	Sub-field	Full text	Key words	IPC4
Biotechnology	Target identification technology	Target identification is important for developing new drugs, biodiagnostics, and biotreatment. Efforts shall be focused on studying scale identification of key genetic functions and their regulatory networks in the physiological and pathological process, making breakthroughs in techniques for identification of functions of disease-causing genes, expression manipulation, target screening, and verification, and innovative new drug manufacturing from “gene to drug”.	Target identification; scale identification; genetic functions; regulatory networks; physiological and pathological process; disease-causing genes; expression manipulation; drug manufacturing	C12N G06F C07K
	Plant-animal varieties and drug molecular design technology	Plant-animal species and drug molecular design technology is made up of molecule docking, molecule simulation, and molecule design based on biomacromolecules’ 3-D structures. Priorities shall be given to studying protein and dynamic cellular process and associated bioinformatic analysis, consolidation, and simulation. Develop virtual plant-animal species and drug design technology, simulation technology for plant-animal species growth and pharmaceutical metabolism engineering, computer aided composite bank design, synthesizing, and screening.	Plant-animal species; drug molecular design technology; molecule docking; molecule simulation; molecule design; biomacromolecules’ 3-D structures; protein and dynamic cellular process; bioinformatic analysis; consolidation and simulation; virtual plant-animal species; drug design technology; simulation technology; plant-animal species growth; pharmaceutical metabolism engineering; computer aided composite bank design; synthesizing, and screening	G06F C12N C07K
	Gene manipulation and protein engineering technology	Gene manipulation technology is a key link to the utilization of genetic resources. Protein engineering constitutes an important approach to efficient utilization of genetic products. Efforts will be focused on developing technologies for highly effective expression and regulation, chromosome structuring and positioning, coded protein gene design and transformation technology, protein peptide chain decoration and restructuring technology, protein structure analyzing technology, and scale protein isolation and purification technology.	Gene manipulation technology; utilization of genetic resources; protein engineering; utilization of genetic products; expression and regulation; chromosome structuring and positioning; coded protein gene design and transformation technology; protein peptide chain decoration and restructuring technology; protein structure analyzing technology; scale protein isolation and purification technology	C12N C07K G06F
	Stem cell based human tissue engineering technology	Stem cell technology is a process that can be used to develop in-vitro stem cells, or harvest different tissues or cells clinically needed through directional induced differentiation or isolation. It also can construct in-vitro human organs for replacement and repairing treatment. Priorities shall be to develop therapeutic cloning technology, in-vitro stem cells construction and directional induction technology, in-vitro human tissue construction and associated scale production technology, multiple human cell-based sophisticated tissue construction and dysfunction repairing technology, and biomanufacturing technology.	Stem cell technology; in-vitro stem cells, directional induced differentiation or isolation; in-vitro human organs for replacement and repairing treatment; therapeutic cloning technology; in-vitro stem cells construction and directional induction technology; in-vitro human tissue construction and associated scale production technology; multiple human cell-based tissue construction; dysfunction repairing technology; biomanufacturing technology.	C12N A61K

Continued on next page.

Table A.5 continued from previous page

Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Next-generation Industrial biotechnology	Biocatalysis and biotransformation constitute the mainstream of the new generation industrial biotechnology. Priorities will be to develop scale screening technology for functional strains, directional biocatalyst upgrading technology, biocatalysis technology system for scale industrial production, clean transformation media manufacturing technology, and associated industrialized transformation process.	Biocatalysis; biotransformation; industrial biotechnology; scale screening technology for functional strains; directional biocatalyst upgrading technology; biocatalysis technology system for scale industrial production; clean transformation media manufacturing technology; industrialized transformation process	C12P C12N C10G
Information Technology	Intelligent sensing technology	Research will be focused on intelligent information processing and control technologies based on biological characteristics and image and natural language comprehension and centered on humans, while developing processing systems for Chinese language information, systematic technologies involving biological characteristics identification, and intelligent traffic systems	Intelligent information processing; control technologies; biological characteristics; image and natural language comprehension; processing systems; Chinese language information; systematic technologies; biological characteristics identification; intelligent traffic systems	G06F G08G H04W
	Ad hoc network technology	Priorities will be to develop technologies for ad hoc mobile networks, ad hoc computing networks, ad hoc storage networks, and ad hoc sensor networks, low-cost real-time information processing systems, multi-sensor information integration, individualized interactive interface, high-flexibility attack free data networks, advanced information security systems, and ad hoc intelligent system and intelligent personal system.	Ad hoc mobile networks; ad hoc computing networks; ad hoc storage networks; ad hoc sensor networks; low-cost real-time information processing systems; multi-sensor information integration; individualized interactive interface; high-flexibility attack free data networks; information security systems; ad hoc intelligent system, ad hoc intelligent personal system.	H04W H04L G01W
	Virtual reality technology	Research will be focused on technologies for integrating different disciplines, including electronics, psychology, cybernetics, computer graphics, database design, real-time distribution system, and multimedia technology in addition to studying virtual reality technologies and associated systems for related fields, including medicine, entertainment, arts, education, military affairs, and industrial manufacturing management.	Integration; electronics; psychology, cybernetics; computer graphics, database design; real-time distribution system; multimedia technology; virtual reality technologies; medicine; entertainment; arts; education; military affairs; industrial manufacturing management.	A61M G06Q G09B
Advanced Materials Technology	Intelligent materials and structural technology	Intelligent materials and intelligent structures constitute a smart or intelligent structural systems that integrate sensors, control, and drive (execution) and other functions. Priorities will be to develop technologies for intelligent material manufacturing and processing, intelligent structure design and manufacturing, key equipment monitoring, and failure control.	Intelligent materials; intelligent structures; intelligent structural systems; integration; sensors; control, drive execution; intelligent material manufacturing; processing; intelligent structure design; manufacturing; key equipment monitoring; failure control.	H04Q G06F G05D
	High-temperature superconducting technology	Research will be focused on novel high-temperature superconducting materials and associated manufacturing technology, superconducting cables, superconducting motors, and high performance superconducting electric devices while studying a range of sensitive detecting devices such as superconducting biomedical elements, high-temperature superconducting filters, high-temperature superconducting injury-free detectors, and scanning magnetic microscopes.	High-temperature superconducting materials; manufacturing technology; superconducting cables; superconducting motors; high performance superconducting electric devices; sensitive detecting devices; superconducting biomedical elements; high-temperature superconducting filters; high-temperature superconducting injury-free detectors; scanning magnetic microscopes.	G02B H02H H01L

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Table A.5 continued from previous page

Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Efficient energy material technology	Research will be focused on critical technologies for solar cell related materials and associated key technologies, critical technologies for fuel cell materials, high volume hydrogen storage material technology, efficient rechargeable cell materials and associated key technologies, key super capacitor materials and associated manufacturing technology, and efficient energy conversion and storage material systems.	Solar cell related materials; fuel cell materials; high volume hydrogen storage material technology; rechargeable cell materials; super capacitor materials; manufacturing technology; energy conversion; storage material systems	H01L H01G H01M
Advanced Manufacturing Technology	Extreme manufacturing technology	Extreme manufacturing refers to the manufacturing components or functional systems at an extreme scale (extremely large or extremely small) or with extremely powerful functions under extreme conditions or environment. Research will be focused on design, manufacturing, and test technologies for micro and nanometer electro-mechanic systems, and technologies for micro and nanometer manufacturing, super precision manufacturing, giant system manufacturing, and intense field manufacturing	Manufacturing components; functional systems; extreme scale; extremely large; extremely small; extremely powerful functions; extreme conditions; extreme environment; design; manufacturing; test technologies; micro electro-mechanic systems; nanometer electro-mechanic systems; micro manufacturing; nanometer manufacturing; super precision manufacturing; giant system manufacturing; intense field manufacturing	C10M G03F B03C
	Intelligent service robotics	An intelligent service robot is an intelligent equipment integrated with a number of high-tech elements, able to provide diverse services needed by humans, in a non-structural environment. The focus will be on service robots and dangerous operation robots in order to study common basic technologies, including design approaches, manufacturing techniques, intelligent control, and application system integration	Intelligent service robot; intelligent equipment; high-tech elements; non-structural environment; service robots; dangerous operation robots; common basic technologies; design approaches; manufacturing techniques; intelligent control; application system integration	B25J B05B B62D
	Service life prediction technology for major products and facilities	Service life prediction technology for major products and facilities represents a key technology for improving operational reliability, safety, and maintainability. Efforts will be made to study prediction control and optimization technology for elements design for components and prototyping process, knowledge-based prototyping and simulation technology, onsite manufacturing process test and evaluation technology, component service life prediction technology, and reliability, safety, and service life prediction technology for major products, complex systems, and large facilities	Service life prediction technology; operational reliability; safety; maintainability; prediction control; optimization technology; elements design; components; prototyping process; knowledge-based prototyping; simulation technology; onsite manufacturing process test; evaluation technology, components; complex systems; large facilities	B29C G06F G05B
Advanced Energy Technology	Hydrogen and fuel cell technology	Research efforts will focus on technologies for making hydrogen through the use efficient low-cost fossil fuel energy and renewable energy, cost-effective hydrogen storage and transport, technologies for manufacturing basic key fuel cell components, thermopile integration, fuel cell applications to power generation and automobile propulsion systems. Efforts will also be made to develop technical standards for hydrogen energy and fuel cell technology.	Hydrogen production; low-cost fossil fuel energy; renewable energy; cost-effective hydrogen storage; transport, manufacturing fuel cell components; thermopile integration; fuel cell applications; power generation; automobile propulsion systems; technical standards for hydrogen energy; fuel cell technology	G01J B63H G06Q

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Table A.5 continued from previous page

Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Distributive energy supply technology	Distributive energy supply technology constitutes an important means of providing comprehensive energy services featured with flexibility and energy efficiency. The focus will be on mastering technologies for fossil fuel-based mini gas turbines and energy conversion such as innovative thermal cycle, energy storage, and triple-generation technology, with view to establishing renewable energy based distributive terminal energy supply systems made up of mini gas turbines and fuel cells, supplemented by fossil fuel energy	Distributive energy supply technology; energy services; fossil fuel-based mini gas turbines; energy conversion; thermal cycle; energy storage; triple-generation technology; renewable energy based distributive terminal energy supply systems; mini gas turbines; fuel cells; fossil fuel energy	H01P C10G H04Q
	Fast neutron reactor technology	A fast neutron reactor is a nuclear reactor where fission chain reaction is triggered by fast neutrons to realize nuclear fuel breeding. It is capable of full utilization of uranium resource in addition to handling long-life span radioactive wastes. Conduct research on and master fast neutron reactor design and core technologies, nuclear fuel and structural materials, while striving for major technological breakthroughs in sodium cycle, developing a 65MW experimental fast reactor for critical and grid power generation	Fast neutron reactor; fission chain reaction; fast neutrons; nuclear fuel breeding; uranium resource; long-life span radioactive wastes; fast neutron reactor design; core technologies; nuclear fuel materials; structural materials; sodium cycle; grid power generation	G21C G21F G01T
	Magnetic contained fusion technology	Taking advantage of participating in research on and construction of the International Thermal-nuclear Experimental Reactor project, focus our research on technologies concerning large superconducting magnets, microwave heating and driving, neutral beam injection heating, blanketing, large real-time tritium isolation and purification, diverters, numerical modeling, plasma control and diagnosis, and key materials for an experimental reactor. Deepen the study of high-temperature plasma physics and exploring non-Tokamak approaches for some energy applications	Thermal-nuclear reactor; large superconducting magnets; microwave heating; microwave driving; neutral beam injection heating; blanketing, large real-time tritium isolation; purification; diverters; numerical modeling, plasma control; diagnosis; high-temperature plasma physics; non-Tokamak approaches; energy applications	G21C G21B H05H
Marine Technology	3-D marine environment monitoring technology	3-D marine environment monitoring is a technology designed for synchronized monitoring of marine environmental elements from space, offshore stations, water surface, and in-water. Research will be focused on remote marine sensing technology, acoustic probe technology, buoy technology, shore-based long-range radar technology, and marine information processing and application technology	3-D marine environment monitoring technology; synchronized monitoring; marine; space; offshore stations; water surface; in-water; remote marine sensing technology; acoustic probe technology; buoy technology, shore-based long-range radar technology; marine information processing; application technology	G01S B63B G01V
	Ocean floor based multi-parameter fast sounding technology	Sea-floor based multi-parameter sounding is a technology for synchronized collection of different parameters, including sea-floor geophysics, geochemistry, and biochemicals, capable of transmitting information and data on a real-time basis. Research priority will be on sensor technology, automatic sensor positioning technology, and sea-floor information transmission technology under abnormal environment and conditions	Sea-floor based multi-parameter sounding technology; synchronized parameter collection; sea-floor geophysics; geochemistry; biochemicals; real-time basis information and data transmission; sensor technology; automatic sensor positioning technology; sea-floor information transmission technology; abnormal environment; abnormal conditions	G01N G01V H01J
	Natural gas hydrate exploitation technology	Natural gas hydrate is a carbon nitrate bedded at the deep seafloor or underground. Research will focus on prospecting theory and exploitation technology for such a compound, geophysics and geochemistry based gas hydrate prospecting and assessing technology. Strive for breakthroughs in gas hydrate drilling technology and safe mining technology.	Natural gas hydrate; carbon nitrate; prospecting theory; exploitation technology; geophysics; geochemistry; gas hydrate prospecting; assessing technology; gas hydrate drilling technology; safe mining technology.	G01V G01N E21B

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Table A.5 continued from previous page

Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Deep-sea operation technology	Deep-ocean operation technology is an under-water process for deep seafloor engineering operation and mining activities. Research focus will be on underwater carrying technology at a large depth, life maintaining system technology, high-power dynamic device technology, high fidelity sample collection and distance information transmission technology, deep-sea operational equipment manufacturing technology, and deep-sea space station technology	Deep-ocean operation technology; under-water process; deep seafloor engineering operation; mining activities; underwater carrying technology; large depth; life maintaining system technology; high-power dynamic device technology; high fidelity sample collection; distance information transmission technology; deep-sea operational equipment manufacturing technology; deep-sea space station technology	E21C F03B F16C
Laser Technology		Laser technology	Laser technology	H01S B41C B61K
Aerospace Technology		Aerospace Technology	Aerospace technology	C22F B64G B64C

**Table A.6:** Concordance table SEI - IPC4. Source: Authors (Keywords), SEI (Field, subfield, Full text), WIPO website (Explanation IPC4)([http://www.wipo.int/ipc/itos4ipc/ITSupport\\_and\\_download\\_area/](http://www.wipo.int/ipc/itos4ipc/ITSupport_and_download_area/))

Field/industries targeted	Sub-field	Full text	Key words	IPC4
Energy conservation and environmental protection industries	Energy efficiency industry	Focus on the development of efficient internal combustion engines and hybrid vehicles, high frequency control, rare earth permanent magnet coreless motor and other electrical energy-saving technology, regenerative high temperature air combustion, plasma ignition, such as efficient boiler furnace technology, high efficiency heat exchanger device and system optimization echelon energy utilization technology, the use of low-grade waste heat and pressure recovery technology, energy optimization technology.	Efficient internal combustion engines; hybrid vehicles; high frequency control; rare earth permanent magnet coreless motor; electrical energy-saving technology; regenerative high temperature air combustion; plasma ignition; efficient boiler furnace technology; high efficiency heat exchanger device; system optimization echelon energy utilization technology; low-grade waste heat and pressure recovery technology; energy optimization technology	F01K F28D F23L
	Advanced environmental protection industry	Accelerate the implementation of water pollution control and management technology major projects, focusing on the development of membrane technology, biological nitrogen removal, heavy metal waste water pollution control, sewage treatment sludge treatment and disposal of key technologies, incineration flue gas control system, leachate treatment waste disposal technology, and efficient dust removal, desulfurization and denitrification and other air pollution control technology, prevention and treatment of toxic and hazardous pollutants and the safe disposal technology, electrical and electronic products toxic and hazardous substances and alternative reduction technology, heavy metal pollution and soil restoration technology and complete sets equipment, new efficient environmentally friendly materials.	Water pollution control and management technology; membrane technology; biological nitrogen removal; heavy metal waste water pollution control; sewage treatment sludge treatment; incineration flue gas control system; leachate treatment waste disposal technology; efficient dust removal; desulfurization; denitrification; air pollution control technology; prevention and treatment of toxic and hazardous pollutants technology; safe disposal technology; electrical and electronic products toxic and hazardous substances and alternative reduction technology; heavy metal pollution and soil restoration technology; complete sets equipment; new efficient environmentally friendly materials	C02F B01D F23G
	Resource recycling industry	Focus on the development of low-grade mineral resources occurred efficient dressing and smelting, rare metals separation and extraction technology, large bulk solid waste utilization high value-added content, waste electrical and electronic products resource utilization, waste material separation and modification, waste car recycling power batteries and battery handling and use, mechanical and electrical products and auto parts re-manufacturing technology, urban and industrial waste production processes co-resource processing, kitchen waste resource utilization, agricultural and forestry waste.	Low-grade mineral resources occurred efficient dressing and smelting; rare metals separation and extraction technology; large bulk solid waste utilization; waste electrical and electronic products resource utilization; waste material separation and modification; waste car recycling power batteries; battery handling and use; mechanical products; electrical products; auto parts re-manufacturing technology; urban and industrial waste production processes; co-resource processing; kitchen waste resource utilization; agricultural and forestry waste	C22B C02F C10B

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Table A.6 continued from previous page

Field/industries targeted	Sub-field	Full text	Key words	IPC4
Next generation IT industry	Next-generation information network industry	Implementation of Things and cloud computing innovation development projects; accelerate IPv4 / IPv6 interworking network devices, and support for IPv6, high-speed, high-performance network and terminal equipment, support systems, network security equipment, testing equipment and related chip development and industrialization, strengthening of TD-SCDMA, TD-LTE and fourth generation mobile communication (4G) and terminal equipment research and development, accelerate high-performance computers, high-end servers, intelligent terminals, network storage, information security and other key information technology equipment R&D and industrialization. To promote the next generation of digital TV transmission technology evolves, the receiving terminal, the core chip, optical communications, high-performance broadband network development and industrialization, promote the triple play intelligent terminals and industrial applications, the establishment of radio and television digital rights technology system.	Implementation of Things; cloud computing; IPv4 / IPv6 interworking network devices; IPv6; high-speed network; high-performance network; terminal equipment; support systems; network security equipment; testing equipment; related chip development; industrialization; TD-SCDMA; TD-LTE; fourth generation mobile communication (4G); terminal equipment; high-performance computers; high-end servers; intelligent terminals; network storage; information security; information technology equipment; digital TV transmission technology; receiving terminal; core chip; optical communications; high-performance broadband network; triple play intelligent terminals; radio and television digital rights technology system	G06F H04N H04W
	Core foundation electronics industry	Accelerate the implementation of core electronic devices, high-end general chips and basic software products major science and technology and great scale integrated circuit manufacturing equipment and complete sets of major science and technology, focusing on the development of mobile Internet, mixed, information security, digital TV , radio frequency identification (RFID), sensors and other chips, 32/28 nanometer advanced technology to promote the industrialization of support RF technology, simulation technology, and other characteristics of process development, to develop advanced packaging and testing technology, the key to strengthening the 8-12 inch production line equipment, apparatus, research and development of materials. Support for semiconductor and optoelectronic devices and new materials preparation technology, high-generation TFT-LCD production line technology, manufacturing equipment and key supporting material preparation technology, high-definition and other new ultra-thin PDP and OLED display technology, and the development of new power electronic devices of key technologies	Core electronic devices; high-end general chips; software; great scale integrated circuit manufacturing equipment; mobile Internet; information security; digital TV; radio frequency identification (RFID); sensors; 32/28 nanometer advanced technology; RF technology; simulation technology; process development; packaging and testing technology; 8-12 inch production line equipment; apparatus; materials; semiconductor devices; optoelectronic devices; new materials preparation technology; high-generation TFT-LCD production line technology; manufacturing equipment; high-definition; ultra-thin PDP and OLED display technology; power electronic devices	H01L G09G

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Table A.6 continued from previous page

Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Emerging high-end software and information services industry	In mobile intelligent terminal software, network computing platform and supporting software, intelligent mass data processing related software development and industrialization. Organization and implementation of search engines, virtual reality, cloud computing platform, digital rights systems research and development. Promote information security critical product development and industrialization. Strengthen computer-aided design and manufacturing, intelligent management software and other industrial research and development. Encourage independent research and development in the field of electronic government, finance, telecommunications, insurance, transportation, radio and television and other major information systems. Strengthening information systems consulting and design, integration implementation, system operation and maintenance, testing and evaluation support in areas such as technology development. Organization and implementation of digital content common key technology research and industrialization. Strengthen biometric identification and authentication technology development and application of new high-end software and information services industry	Mobile intelligent terminal software; network computing platform; supporting software; intelligent mass data processing related software; search engines; virtual reality; cloud computing platform; digital rights systems; information security; computer-aided design; manufacturing; intelligent management software; electronic government; finance; telecommunications; insurance; transportation; radio and television; information systems; information systems consulting; design; integration implementation; system operation; maintenance; testing; evaluation support; technology development; digital content; biometric identification; authentication technology; high-end software; information services industry	G06F G06Q
Bio-industry	Bio-pharmaceutical industry	Innovation capacity building: the establishment of national genetic resource library, protein library and biobanking; chemical pharmaceutical formulation technology, animal cells and efficient expression of mass culture, recombinant therapeutic antibodies, synthetic peptide drugs, stem cell therapy, gene therapy, Translational medicine as the focus, relying on the advantages of building a sound business health research closely integrated drug discovery platform. Drug Discovery: accelerate the implementation of prevention and treatment of major science and technology to create new drugs, AIDS and viral hepatitis and other major infectious diseases of major projects, R & D cancer prevention, cardiovascular disease, diabetes and other serious diseases innovative drugs, new drugs and new drug safety evaluation carried out clinical research. Industrialization: the implementation of genetically engineered drugs and vaccines innovation development projects; to promote intellectual property rights of genetic engineering drugs, vaccines, antibody drugs, chemical drugs, natural medicine, modern medicine new varieties, new Chinese Herbal Medicine, Chinese herbal medicines standardized planting of industrialization; promotion of large-scale animal cell culture, protein purification and other support capabilities of new technology and new pharmaceutical production equipment	Genetic resource library; protein library; biobanking; chemical pharmaceutical formulation technology; animal cells; expression of mass culture; recombinant therapeutic antibodies; synthetic peptide drugs; stem cell therapy; gene therapy; Translational medicine; drug discovery platform; prevention; treatment; disease; drugs, AIDS; viral hepatitis; cancer prevention, cardiovascular disease; diabetes; new drug safety evaluation; clinical research; genetically engineered drugs; vaccines; antibody drugs; chemical drugs; natural medicine; Chinese Herbal Medicine; large-scale animal cell culture; protein purification; pharmaceutical production equipment	A61K C12N C07K

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Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Biomedical engineering industry	Support for biomedical research, clinical research and development of high-performance core components of diagnostic equipment and key technologies, develop high integration, high sensitivity, high specificity and high stability of the clinical diagnosis, treatment equipment and reagents, and promote tissue engineering, and minimally invasive interventional treatment, rehabilitation and other product development, development of digital, mobile medical systems and primary health care institutions suitable for high-cost medical equipment	Biomedical research; clinical research; high-performance core components; diagnostic equipment; high integration; high sensitivity; high specificity; high stability; clinical diagnosis; treatment equipment; reagents; tissue engineering; minimally invasive interventional treatment; rehabilitation; digital systems; mobile medical systems	A61B A61L C12N
	Biological agriculture industry	Accelerate the implementation of genetically modified organisms cultivate new varieties of major science and technology; breakthrough transgenic breeding, space breeding, molecular marker breeding, heavy ion irradiation breeding bio-breeding and green agricultural biological products key technology, accelerate the development of important agricultural biological new varieties , as well as disease prevention and control of major agricultural production of new vaccines, biological pesticides and other agricultural products green.	Genetically modified organisms; transgenic breeding; space breeding; molecular marker breeding; heavy ion irradiation breeding bio-breeding; green agricultural biological products technology; agricultural biological new varieties; disease prevention; new vaccines; biological pesticides; agricultural products	C10N C07K A01K
	Bio-manufacturing industry	Supports advanced bio-manufacturing technology research and development, improve the microbial gene resource center and information base, the key technology breakthrough bio-based raw materials, large-scale production process, non-food feedstock, synthetic biology, engineering bacteria development, the development of the chemical, light industry, textile and other industries biological production process	Bio-manufacturing technology; microbial gene resource center; information base; bio-based raw materials; large-scale production process; non-food feedstock; synthetic biology, engineering bacteria; chemical light industry; textile; biological production process	C12N C02F G01N
High-end equipment manufacturing industry	Aviation equipment industry	Accelerate the implementation of major science and technology of large aircraft to carry out a large commercial turbofan engine development. Strengthen the overall aircraft and helicopters designed and tested; enhance aviation new materials and parts manufacturing, aerospace equipment and systems, new turboshaft engine, airworthiness, air traffic control systems and other key technology research and development	Large aircraft; turbofan engine; aircraft; helicopter; aviation new materials; parts; manufacturing; aerospace equipment; aerospace systems; turboshaft engine; airworthiness; air traffic control systems	B64C F02C B64D
	Satellite and industrial applications	Breakthrough satellite long life and high reliability, advanced technology and key satellite platform, the new satellite payload, quantitative application of satellite remote sensing, high-precision satellite navigation, broadband satellite communications, heavy launch vehicle, integrated spatial information applications, integrated development operational satellite system; promote stratospheric airship, space weather and other key technologies	Satellite; reliability; satellite platform; satellite payload; satellite remote sensing; high-precision satellite navigation; broadband satellite communications; heavy launch vehicle; integrated spatial information applications; integrated development operational satellite system; promote stratospheric airship; space weather	B64B B64G H04B

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Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Rail transportation equipment industry	implementation of advanced rail transportation equipment and key components of innovation and development projects; rapid completion of AC drive locomotive axle length grouping large heavy freight train technology research; to promote the comprehensive testing train, alpine EMU, intercity trains intelligent train development work to achieve EMU and product genealogy of AC drive locomotive, and gradually improve low-speed maglev technology innovation, high-speed magnetic levitation guide basic grasp and traction control, large-scale conservation of key technology and equipment manufacturing; development of modern trams; development of new train control system, comprehensive security testing and other key technologies.	Rail transportation equipment; AC drive locomotive axle length grouping large heavy freight train technology; alpine EMU; intercity trains intelligent train; EMU; product genealogy of AC drive locomotive; low-speed maglev; high-speed magnetic levitation guide basic grasp; traction control; trams; train control system; security testing	B60L B61L B61B
	Marine engineering equipment industry	Implementation of marine engineering equipment industrial innovation development projects, basic grasp of major offshore oil and gas equipment independently developed design and construction technology to improve the key equipment and systems supporting capacity. Breakthroughs in key technologies of marine wind energy construction equipment, marine observation monitoring equipment and systems, surface support systems, underwater operations and security equipment. Actively carry out deep-sea station, a large floating offshore structures and other marine renewable energy research and development, metal seabed mineral resources development and other forward-looking technology and equipment	Marine engineering equipment; offshore oil and gas equipment; marine wind energy construction equipment; marine observation monitoring equipment; systems; surface support systems; underwater operations; security equipment; deep-sea station; floating offshore structures; marine renewable energy; metal seabed mineral resources	B63B F03D E02B
	Intelligent manufacturing equipment industry	Accelerate the implementation of high-end CNC machine tools and basic manufacturing equipment technology major projects. Strengthen new sensing, precision motion control, optimization control key technology research and system integration and public service platform; increase of new sensors, intelligent instruments, precision testing equipment, automatic control systems, high-performance hydraulic parts, industrial robots and other typical capability of independent innovation of intelligent devices	High-end CNC machine tools; manufacturing equipment technology; sensing; precision motion control; optimization control; system integration; public service platform; sensors; intelligent instruments; precision testing equipment; automatic control systems; high-performance hydraulic parts; industrial robots; intelligent devices	G05B B25J B23Q

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Field/industries targeted	Sub-field	Full text	Key words	IPC4
New energy industry	Nuclear technology industry	Strengthen nuclear safety, research and other technical processing and reprocessing of nuclear fuel waste disposal, in ensuring the safety of the premise, to carry out the safe operation of nuclear power generation in transportation technology and life extension technology development, speed up the digestion third-generation nuclear power technology absorption and re-innovation, to carry out co-ordination The third-generation nuclear power plant construction. The implementation of large-scale advanced pressurized water reactor nuclear power plant and the HTR technology major projects, construction of demonstration projects. Fast reactor research and development and other fourth-generation nuclear reactors and small reactor technology, timely start demonstration projects. Development of nuclear fuel and nuclear power equipment manufacturing industry chain. 2015, master advanced nuclear technology, complete sets of equipment manufacturing capacity to improve, to achieve self-reliance of nuclear power development; operation of nuclear power installed capacity reached 40 million kilowatts, including three generations, including nuclear power equipment manufacturing capacity stable at 10 million kilowatts or more. By 2020, the formation of million-kilowatt nuclear advanced technology development, design, equipment manufacturing capacity internationally competitive.	Nuclear safety; technical processing; reprocessing; nuclear fuel waste disposal; nuclear power generation; transportation technology; life extension technology; digestion third-generation nuclear power technology absorption; third-generation nuclear power plant construction; large-scale advanced pressurized water reactor nuclear power plant; HTR technology; fast reactor; fourth-generation nuclear reactors; reactor technology; nuclear fuel; nuclear power equipment manufacturing	G21C G21D G21F
	Wind energy industry	Establishment of wind power technology research and development institutions, to break wind machine design and bearing, converter and control systems manufacturing technology and equipment bottlenecks. Our development and adapt to climate and geographical features of wind power technology and equipment, 3-5 megawatt machine, the new wind turbine and its key components industrialization, meet the land, offshore wind farm construction needs	Wind power technology; wind machine design; bearing; converter; control systems manufacturing technology; wind power technology; equipment; wind turbine; components; land; offshore wind farm construction	F03D H05K A01B
	Solar industry	Focus on the development of solar energy equipment production of new technology and new equipment to improve the conversion efficiency of solar photovoltaic cells, battery components to reduce the cost of key technologies; the development of solar photovoltaic-based distributed energy systems; development of solar photovoltaic generation of new materials, new generation of solar cells, solar thermal power generation and heat storage technology; the use of solar thermal diversified technology, refrigeration technology and industrial applications, complementary scenery storage technology. Development of energy storage technologies and equipment	Solar energy equipment production; conversion efficiency; solar photovoltaic cells; battery components; solar photovoltaic-based distributed energy systems; photovoltaic generation of new materials; new generation of solar cells; solar thermal power generation; heat storage technology; solar thermal diversified technology; refrigeration technology; industrial application; scenery storage technology; energy storage technologies; equipment	H01L F24J H02J

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Field/industries targeted	Sub-field	Full text	Key words	IPC4
	Biomass industry	Promoting large-scale automated machinery to collect straw, organic waste as raw material for small movable biogas purification canning equipment development and promotion; support efficient biomass briquette processing equipment and equipment development and biomass gasification industrialization; complete megawatt diesel generating units and low calorific value gas megawatt gas turbine industrialization; built 10 ton of sweet sorghum ethanol demonstration project; strengthen bioenergy plant breeding and industrial raw materials; low cost fiber luciferase, microalgae biodiesel technological breakthroughs	Large-scale automated machinery; collection; straw; organic waste; raw material; movable biogas purification canning equipment; efficient biomass briquette processing equipment; biomass gasification industrialization; complete megawatt diesel generating units; low calorific value gas megawatt gas turbine; sweet sorghum ethanol; bioenergy plant breeding; industrial raw materials; low cost fiber luciferase; microalgae biodiesel technological	C12P C10L C12N
New materials industry	New functional materials industry	Develop rare earth permanent magnet, luminescence, catalysis, hydrogen storage and other high-performance rare earth functional materials and rare earth resources and efficient utilization technology. Actively develop high-purity rare metals and targets, nuclear grade zirconium, tungsten and molybdenum materials and high-end products, accelerate high-purity silicon materials, new semiconductor materials, magnetic materials, high-performance membrane materials industry. Efforts to expand the scale of production of butyl rubber, nitrile rubber, isoprene rubber, fluoro silicone rubber, ethylene propylene rubber, special rubber and high-end thermoplastic elastomers, accelerate the development of high-end varieties and special additives. Develop low-E coated glass, solar ultra-white glass, flat panel display glass, new ceramic functional materials, piezoelectric materials, inorganic nonmetallic materials. Actively develop high-purity graphite, artificial crystals, superhard materials and products.	Rare earth permanent magnet; luminescence; catalysis; hydrogen storage; high-performance rare earth functional materials; rare earth resources; utilization technology; high-purity rare metals; nuclear grade zirconium; tungsten; molybdenum materials; high-end products; high-purity silicon materials; new semiconductor materials; magnetic materials; high-performance membrane materials industry; butyl rubber; nitrile rubber; isoprene rubber; fluoro silicone rubber; ethylene propylene rubber; special rubber; thermoplastic elastomers; varieties; special additives; low-E coated glass; solar ultra-white glass; flat panel display glass; ceramic functional materials; piezoelectric materials; inorganic nonmetallic materials; high-purity graphite; artificial crystals; superhard materials	C08K C04B
	Advanced structural materials industry	With lightweight, high strength, large size, vigorously develop high-strength light alloy, and actively develop high-performance aluminum alloy, magnesium alloy to accelerate the preparation and processing, development of high-performance alloys, titanium large, strip and welded pipe. To protect the high-end equipment manufacturing and major construction projects focus on accelerating the development of high-quality special steel and high temperature alloys. Strengthening of engineering plastics modification and processing applications technology development, vigorously develop polycarbonate, polyamide, polyacetal and special epoxy resin	Lightweight; high strength; large size; high-strength light alloy; high-performance aluminum alloy; magnesium alloy; preparation; processing; high-performance alloys; titanium large; strip; welded pipe; high-end equipment manufacturing; high-quality special steel; high temperature alloys; engineering plastics modification; processing applications technology; polycarbonate; polyamide; polyacetal; special epoxy resin	C08L C22C C23C
	High-performance composite materials industry	Accelerating breakthrough new materials advanced manufacturing technology and equipment, and promote high-performance composite materials, advanced structural materials, new functional materials development and industrialization. Preparation and processing of new materials and development of key technology and complete sets of technology, a number of key construction materials industrialization demonstration production line, nurture and develop a number of new materials industry base	New materials advanced manufacturing technology; equipment; high-performance composite materials; structural materials; new functional materials; preparation; processing of new materials; construction materials	C08G C12N C22C

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Table A.6 continued from previous page

Field/industries targeted	Sub-field	Full text	Key words	IPC4
New energy automotive industry		Implementation of new energy vehicles major innovation projects, to break through the process of structural lightweight body materials and other common techniques and technology, research and development of new energy vehicles new chassis, powertrain, automotive electronics and other products, to increase joint efforts to develop power battery and key materials, and the production, control and testing equipment, etc., to build industry-wide sharing common technology platform. Establish and improve the new energy vehicles, charging technology and facility standards	New energy vehicles; structural lightweight body materials; techniques; new energy vehicles new chassis; powertrain; automotive electronics; power battery; production; control; testing equipment; technology platform; charging technology; facility standards	B62D B60K B22F

## **Appendix B**

# **Going Out to Innovate More at Home: Impacts of Outward Direct Investments on Chinese Firms' Domestic Innovation Performance**

	Mean	St. Dev.	Min	Max
R&D Intensity	0.039	0.042	0.000	0.991
Patent Apps (ln)	0.210	0.706	0.000	8.677
Patents Granted (ln)	0.123	0.508	0.000	8.185
Patent Cites (ln)	0.030	0.176	0.000	3.497
Patent Claims (ln)	0.209	0.613	0.000	3.994
EBITDA/Assets (ln)	0.096	0.071	0.001	1.116
Treatment	0.039	0.193	0	1
Post-Treatment ( $t + 1$ )	0.032	0.176	0	1
Post-Treatment ( $t + 2$ )	0.026	0.158	0	1
Post-Treatment ( $t + 3$ )	0.020	0.141	0	1
Patent Stock (ln)	1.065	1.587	0.000	10.623
SOE (0=No, 1=Yes)	0.467	0.499	0	1
No. Employee (ln)	7.325	1.399	0.693	13.223
Operating Revenue (ln)	20.805	1.692	0.000	28.689
Fixed Assets (ln)	19.617	1.864	0.000	27.320
Intangible Assets (ln)	17.686	2.146	0.000	25.723

**Table B.1:** Summary statistics

	Patent Apps	Patent Granted	Patent Cites	Patent Claims	R&D Intensity	EBITDA/ Assets	Treatment	Patent Stock	SOE	Emp.	Operating Revenue	Fixed Assets
Patent Apps												
Patents Granted	0.849											
Patent Cites	0.432	0.364										
Patent Claims	0.842	0.673	0.465									
R&D Intensity	0.099	0.045	-0.009	0.098								
EBITDA/Assets	0.223	0.188	0.056	0.137	-0.283							
Treatment	0.187	0.146	0.039	0.123	-0.037	-0.073						
Patent Stock	0.858	0.670	0.326	0.772	0.099	0.220	0.196					
SOE	-0.025	0.006	-0.002	-0.086	-0.195	0.290	0.078	-0.046				
Employee	0.258	0.216	0.088	0.181	-0.250	0.669	0.219	0.270	0.280			
Operating Revenue	0.244	0.202	0.077	0.163	-0.357	0.831	0.237	0.259	0.308	0.739		
Fixed Assets	0.200	0.158	0.055	0.131	-0.323	0.714	0.209	0.228	0.362	0.743	0.719	
Intangible Assets	0.208	0.152	0.041	0.156	-0.215	0.545	0.191	0.252	0.187	0.581	0.560	0.654

Notes: Coefficients are statistically significant at least at the .1 level.

**Table B.2:** Correlation Matrix

	<i>R&amp;D intensity</i>	<i>Patent Apps</i>	<i>Patents Granted</i>	<i>Patent Claims</i>	<i>EBITDA/ Assets</i>
	(1)	(2)	(3)	(4)	(5)
≥ 5 years before Treatment	-0.005 (0.006)	0.152 (0.092)	0.134 (0.078)	0.051 (0.035)	-0.160 (0.092)
4 years before Treatment	-0.007 (0.006)	-0.057 (0.090)	0.077 (0.076)	-0.019 (0.034)	-0.134 (0.090)
3 years before Treatment	-0.006 (0.006)	0.079 (0.095)	0.097 (0.080)	0.023 (0.035)	-0.002 (0.094)
2 years before Treatment	0.006 (0.006)	0.142 (0.101)	0.115 (0.086)	0.013 (0.038)	-0.003 (0.101)
1 year before Treatment	0	0	0	0	0
≥ 1 year after Treatment	0.012 (0.007)	0.157 (0.111)	0.102 (0.094)	0.024 (0.041)	-0.088 (0.111)

Notes: Parallel trend test is applied to test if there is no significant difference in the pre-trends between ODI firms and non-ODI firms for each outcome variable of interest, with the reference year being the year prior to cross-border M&A.

**Table B.3:** Parallel trends test

## **Appendix C**

# **International Collaboration for a Catch-up in Innovation? The Case of Chinese Co-inventions in Europe**

<b>Variable</b>	<b>Mean</b>	<b>Std. Dev.</b>	<b>Min.</b>	<b>Max.</b>	<b>N</b>
Number of (#) forward citations	0.367	0.885	0	19	25606
# claims	13.437	5.779	1	98	25606
Family size	4.246	2.229	1	30	25606
International co-invention (IntCoinv)	0.033	0.179	0	1	25606
# inventors	2.793	2.127	1	28	25606
Log # inventors (Log Teamsize)	0.787	0.682	0	3.332	25606
# Backward citations (BwdCits)	6.441	3.721	0	120	25606
Log # backward citations (Log BwdCits)	1.899	0.482	0	4.796	25606
# NonPatentLiterature citations (NPLCits)	1.411	4.163	0	219	25606
Log # NonPatentLiterature citations (Log NPLCits)	0.504	0.725	0	5.394	25606
# prior int co-inv stock of firm (Int Coinv Experience)	17.396	39.97	0	254	25606
Log # prior int co-inv stock of firm (Log Int Coinv Experience)	1.293	1.67	0	5.541	25606

**Table C.1:** Summary statistics

Variables	1	2	3	4	5	6	7	8
1 Number of (#) forward citations	1.000							
2 # claims	0.113	1.000						
3 Family size	0.117	0.091	1.000					
4 International co-invention	0.022	0.085	0.060	1.000				
5 Ln # inventors	0.032	0.080	0.063	0.108	1.000			
6 Ln # backward citations	0.004	-0.038	0.043	-0.048	0.021	1.000		
7 Ln # non-patent literature (NPL)	0.070	0.108	0.064	0.027	0.199	-0.198	1.000	
8 Ln # prior co-invention stock per firm	-0.022	0.154	-0.200	0.013	0.007	-0.079	0.106	1.000

Table C.2: Cross-correlation table



## **Invention autochtone, fusions et acquisitions transfrontalières, et collaboration internationale: Essais sur l'émergence de la Chine dans le domaine de l'innovation**

Le sujet de cette thèse de doctorat s'articule autour de l'analyse des politiques de la Chine, des investissements directs étrangers, et de la collaboration internationale en matière d'innovation. Le premier chapitre, co-écrit avec Ilja Rudyk, explore la montée des inventions chinoises en Europe, ainsi que le développement des politiques d'innovation de la Chine. Notre étude évalue les effets de ces politiques sur la propriété nationale dans les technologies stratégiques en utilisant des données sur les brevets européens. De plus, notre méthodologie permet d'évaluer les effets de ces politiques sur les caractéristiques des brevets, reflétant la qualité de ces derniers. Le second chapitre est un travail conjoint avec Anthony Howell et Jia Lin qui examine les effets des fusions et acquisitions transfrontalières sur les innovations chinoises et sur la performance financière des entreprises qui réalisent ces investissements directs étrangers. Le troisième chapitre traite de la relation entre la collaboration internationale et la qualité des brevets en analysant les demandes de brevet chinois en Europe. Il examine la structure des co-inventions internationales chinoises en Europe et analyse le rôle que joue les co-inventions transfrontalières sur la qualité des demandes de brevet chinoises à l'étranger. Ce chapitre contribue ainsi à la compréhension de l'internationalisation et du rattrapage technologique de la Chine.

**Mots-clés:** Chine, politique d'innovation, fusions-acquisitions transfrontalières, collaboration internationale en matière de R&D

## **Indigenous Invention, M&A, and International Collaboration: Essays on China's Rise to Innovation**

The subject of this doctoral thesis revolves around the analysis of China's policies, foreign direct investment, and international collaboration with regard to innovation.

Chapter one, co-written with Ilja Rudyk, explores the rise of Chinese inventions in Europe, China's innovation policies, and assesses their effect with regard to domestic ownership in strategic technologies through the lens of European patent data. Further, our methodology allows for an assessment of effects of the policies on characteristics of the patents, reflecting their quality. Chapter two, joint work with Anthony Howell and Jia Lin, investigates the effects of Chinese cross-border mergers and acquisitions on the domestic innovation activities and financial performance of the firms engaging in such foreign direct investment. The third chapter addresses the relationship between international collaboration and patent quality through an analysis of Chinese patent applications in Europe. It investigates the pattern of Chinese international co-inventions in Europe and scrutinizes the role cross-border co-invention play for the quality of Chinese overseas patent applications. It thereby contributes to the understanding of China's internationalization and technological catch-up.

**Keywords:** China, innovation policy, cross-border M&A, international R&D collaboration