Titre: Title:	Essays into the evolution of systems of innovation: a comparative\phylogenetic tree approach
Auteur: Author:	Ziad Rotaba
Date:	2010
Type:	Mémoire ou thèse / Dissertation or Thesis
Référence: Citation:	Rotaba, Z. (2010). Essays into the evolution of systems of innovation: a comparative\phylogenetic tree approach [Thèse de doctorat, École Polytechnique de Montréal]. PolyPublie. https://publications.polymtl.ca/384/

URL de PolyPublie: PolyPublie URL:	https://publications.polymtl.ca/384/
Directeurs de recherche: Advisors:	Catherine Beaudry
Programme: Program:	Génie industriel

UNIVERSITÉ DE MONTRÉAL

ESSAYS INTO THE EVOLUTION OF SYSTEMS OF INNOVATION: A COMPARATIVE\PHYLOGENETIC TREE APPROACH

ZIAD ROTABA

DÉPARTEMENT DE MATHEMATIQUES ET DE GENIE INDUSTRIEL

ÉCOLE POLYTECHNIQUE DE MONTRÉAL

THÈSE PRÉSENTÉE EN VUE DE L'OBTENTION

DU DIPLÔME DE PHILOSOPHIE DOCTOR (Ph.D)

(GÉNIE INDUSTRIEL)

Juillet 2010

UNIVERSITÉ DE MONTRÉAL

ÉCOLE POLYTECHNIQUE DE MONTRÉAL

Cette thèse intitulée:

ESSAYS INTO THE EVOLUTION OF SYSTEMS OF INNOVATION:

A COMPARATIVE PHYLOGENETIC TREE APPROACH

présentée par : ROTABA Ziad

en vue de l'obtention du diplôme de : Philosophie Docteur (Ph. D)

a été dûment accepté par le jury d'examen constitué de :

Mme DE MARCELLIS-WARIN Nathalie, Doct, président

Mme BEAUDRY Catherine, D.Phil, membre et directeur de recherche

M. WARIN Thierry Ph.D., membre du jury

M. OLLEROS Francisco-Javier, Ph.D. Examinateur externe

DÉDICACE

To my beloved parents, sister and grandparents

ACKNOWLEDGEMENTS

First, I would like to thank Professor Catherine Beaudry. Her carefull reviewing of my original manuscripts, her positive critisim, encouragement, dynamism, positivity and continuous support throught this research work has highly influenced its quality. I am thankful to Carl St-Pierre for his helpful advice on statistical analysis throughout my research period.

I also would like to thank Professor Roger Miller, currently in retirement, for supplying the data and the questionnaire used in this research work, in the scope of the ‘Managing Innovation in the New Economy’ (MINE) project.

I thank all professors at Ecole Polytechnique de Montreal who had a great academic influence on me during the courses, especially Prof. Daniel Leblanc, Prof. Robert Gilbert, and Prof. Jean Charles Bernard.

Finally, I dedicate a special thank you to my friends and collegues for their insightfull discussions, and support during the time I spent in the Industiral Engineering Departement.

RÉSUMÉ

Au cours de la dernière décennie, la littérature sur l'innovation a consacré une attention particulière au secteur de la Haute Technologie (HT). Une telle attention est principalement attribuable au rôle essentiel de la HT afin de contribuer à la croissance économique, à la construction de nouvelles économies et à l'amélioration du bien-être des sociétés. Cette attention croissante en faveur de la HT, a poussé une partie considérable de la littérature sur l'innovation de la traditionnelle basse et moyenne technologie ('Low Medium Techs' ou LMT).

Cet écart au sein de la littérature a attiré l'attention des chercheurs en innovation qui soulignent actuellement le rôle important que le secteur des LMT joue pour pousser la croissance économique et gérer le taux de chômage présentement en augmentation. Cette tentative d'amener une prise de conscience des secteurs universitaire, industriel et financier ne peut pas être isolé du système national d'innovation où ces secteurs sont positionnés. En ajoutant une dimension supranationale, on note qu'une proportion considérable des activités LMT est actuellement en processus de migration des économies avancées vers les économies en phase de rattrapage.

Ce travail de recherche vise à valider trois hypothèses principales. La première traite de la maturité du secteur des HT vis à vis celui des LMT à savoir si nous assistons actuellement à une phase de renouvellement et de transformation suivant la trajectoire du secteur de l'électronique. La seconde porte sur les économies où ces secteurs sont situés, et vise à vérifier si le positionnement dans une économie particulière joue un rôle au niveau de l'innovation du secteur industriel. La troisième hypothèse évalue la faisabilité d'une approche par arbre phylogénétique pour classer les entreprises dans les systèmes d'innovation (secteurs HT et LMT, économies avancées et en phase de rattrapage) et pour vérifier si l'évolution des meilleures pratiques au sein de ces systèmes est réalisable.

Les résultats soutiennent l'hypothèse que les secteurs des HT et des LMT subit un renouvellement sectoriels et une phase de transformation. En outre, puisque les HT et LMT sont des secteurs complémentaires, il est logique de penser que les économies qui excellent dans l'un des secteurs doivent aussi exceller dans l'autre aussi. Ce travail de recherche prouve que si cela est vrai pour les économies en rattrapage, ce ne l'est cependant pas dans le cas des économies avancées. Ces résultats sont aussi validés en utilisant une approche par arbre phylogénétique.

Mots-clés: - innovation, système d’innovation, évolution, économie avancée, économie en phase de rattrapage, haute technologie, basse et moyenne technologies, arbre phylogénétique.

ABSTRACT

In the past decade, the innovation literature has a dedicated special attention to the High Technology (HT) sector. Such an attention was primarily due to the critical role high techs play to foster economic growth, building new economies, and enhancing the well being of societies. This increasing attention has pushed a considerable part of the innovation literature from the traditional Low, Medium Technology (LMT) sectors towards high tech (HT) sectors.

This deviation in the literature has caught the eye of innovation scholars who are currently highlighting the important role that LMT plays to increase economic growth and manage the currently increasing unemployment rates. This attempt to increase the awareness of the academic, industrial and financial sectors to the importance LMT cannot be isolated from the national system of innovation in which those sectors are positioned. Adding a supranational dimension, it is witnessed that a considerable proportion of LMT activities are currently migrating from leading to catching-up economies.

This research work targets three main hypotheses. The first addresses the HT sector maturity and whether we are currently witnessing a renewal and transformation phase, following the trajectory of the electronics sector. The second addressed the economies where those sectors are located. In other words, it assesses whether the innovation strategic context for LMT in leading economies will be as advanced as its HT sector. This level should be similar as well in catching up economies, but with a lesser magnitude then in leading economies. The third hypothesis will assess the feasibility of a phylogenetic tree approach to classify firms within systems of innovation (HT, LMT, Leading and Catching ups) and whether the inference of the evolution of the best practices within these systems is achievable.

The results support the hypothesis that HT and LMT are going through a sectoral renewal and transformation phase. Furthermore, since HT and LMT are complementary sectors, it is predominantly argued that economies excelling in one of the sectors should excel in the other as well. This research work proves that while this is true in catching up economies, it is not however in the case of leading economies. These results were to a great extent validated by using a phylogenetic tree approach.

Keywords: Systems of innovation, evolution, leading economies, catching-up economies, high technology, low and medium technologies, phylogenetic tree.

CONDENSÉ EN FRANCAIS

Ce travail de recherche consiste en une analyse comparative entre les deux secteurs de la basse et moyenne technologie (‘low and medium technology’ ou LMT) et la haute technologie (HT), et les économies avancée et en rattrapage. En premier lieu, les LMT et HT sont d’abord analysées comparativement. En second lieu, une dimension supplémentaire est insérée au niveau de deux groupes d’économies, avancées et en rattrapage. Les deux approches précédentes sont ensuite testés à l’aide d’un arbre phylogénétique, afin de classer les secteurs et les économies, et d’analyser l’évolution des caractéristiques historiquement. Dans l’introduction de cette thèse, nous énonçons trois hypothèses de recherche majeures, la troisième étant plutôt exploratoire, puisqu’elle vise à analyser les systèmes d’innovation (SI), nationaux et sectoriels, dans une perspective évolutive. Les trois hypothèses sont les suivantes :

H1 : Le secteur HT a mûri et nous assistons actuellement à une phase de renouvellement et de transformation, suivant la trajectoire du secteur de l’électronique (Robertson *et al.*, 2009).

H2 : Le contexte stratégique de l’innovation dans les LMT des économies avancées sera aussi avancé que son secteur HT (Robertson et Patel, 2007; Mendonca, 2009). Ce niveau devrait être similaire dans les économies en rattrapage mais d’une moindre ampleur.

H3 : Une approche évolutive utilisant des arbres phylogénétiques est appropriée pour la classification du *système* d’innovation et pour la reconstruction de l’histoire dans une perspective évolutive.

Prenons chacune de ces hypotheses tout à tour et énonçons les conclusions de chaque chapitre, soit des trois articles qui composent cette thèse.

Premiere Hypothèse H1 :

Le secteur HT a mûri et nous assistons actuellement à un renouvellement et une phase de transformation suivant la trajectoire du secteur de l’électronique (Robertson et al., 2009).

Les résultats présentés au chapitre 2 impliquent de grands changements stratégiques pointant vers un processus de renouvellement dans les deux secteurs. Les entreprises de HT, tout en se concentrant sur les produits et l’innovation de rupture qui sont essentielles à des stratégies de différenciation sont aussi occupées par des opérations à grande échelle afin de réduire les coûts. En outre, les entreprises de LMT, caractérisées par l’innovation strategique de procédé et de réduction de coûts visent à différencier leurs produits afin d'éviter la concurrence sévère des faibles coûts du marché. Cette innovation de produit est couplée avec des innovations de procédés traditionnels dans les LMT visant à continuer de soutenir les stratégies de différenciation. Un exemple de ces stratégies consiste à utiliser des produits de haute technologie tels que les produits des GPT pour améliorer le processus de fabrication.

En raison de leur coherence de structure interne de R-D, de leur capacité de produire des technologies à usage général distinguées, les entreprises du secteur HT sont caractérisées par un mécanisme de capacité d'absorption extrêmement efficace, si on la compare aux entreprises de LMT. Toutefois, cette capacité d'absorption est mieux orientée vers l'absorption de connaissances techniques que vers la prévision des mouvements de marché. Par exemple, ceci est représenté par une plus forte prédominance des entreprises de HT, par rapport aux entreprises de LMT, quant à l'importance de la collaboration avec les universities et la production de connaissances scientifiques explicites.

En dépit de la forte dominance du modèle linéaire de l'innovation, les entreprises de HT utilisent efficacement le modèle d'innovation ouverte. Par exemple, on voit que les entreprises continuent de dominer la HT et la production de connaissances par l'interaction entre les entreprises. Cela est probablement dû à la capacité des entreprises de HT à investir dans l'appropriation de leurs connaissances, et de minimiser les risques liés à la collaboration.

Bien que ce soit naturel pour la HT, nos résultats impliquent que le développement des connaissances internes dans les LMT ne faiblit pas en raison de leur dépendance envers les liens externes de génération de connaissances, qui se trouve couramment dans la littérature récente. En fait, elle renforce notre compréhension du renouvellement du secteur des LMT. La littérature récente (par exemple Tsai et Wang, 2009) , bien que centrée sur l'externalisation de l'acquisition des connaissances, démontre que pour les LMT, le développement des connaissances internes est crucial pour renforcer la capacité d'absorption des entreprises. Cette constatation s'appuie sur l'hypothèse de la transformation du secteur des LMT. Dans ce secteur, les entreprises sont désormais plus enclin à produire des connaissances internes afin de réduire les coûts, ou pour minimiser les risques associés aux externalizations.

Alors que les entreprises de HT sont au service des clients complexes, les deux secteurs sont étroitement alignés avec leurs clients, mais pour des objectifs différents. D'une part, les entreprises de HT visent à mieux comprendre les besoins de leurs clients et à produire des produits plus innovants. D'autre part, les entreprises de LMT sont là pour apprendre auprès des clients et sans doute tester les produits qu'ils ne sont pas en mesure de tester à l'interne en raison de contraintes financières.

En général, les gouvernements allouent beaucoup plus de ressources pour soutenir l'innovation dans le secteur HT. En outre, la protection de la propriété intellectuelle est beaucoup plus souvent utilisée pour des innovations des entreprises de HT. Les approbations réglementaires sont utilisées par les deux secteurs, HT et LMT, de façon équivalente. Cette constatation est intéressante, et en contradiction avec notre hypothèse principale pour les LMT. Cette contradiction prend en considération les découvertes récentes de Mendonca (2009) qui suggèrent que les entreprises des LMT sont actuellement à la recherche de l'innovation appropriée et que les forces de réglementation jouent un rôle clé dans ce secteur. Cela se justifie par la prise de conscience accrue du public pour la santé et la sécurité des produits de LMT.

Par conséquent, nos résultats de recherche supportent ceux de Robertson *et al.* (2009). Grâce à notre échantillon, nous démontrons que les deux secteurs des LMT et HT sont dans une phase de transformation et de renouvellement. La HT se transforme pour atteindre plus de maturité, faisant allusion à une transformation possible, comme dans le cas du secteur de l'électronique. Les LMT sont également en transformation au niveau du produit par l'utilisation des technologies à usage général qui ont permis de différencier davantage leurs technologies et de créer de nouveaux marchés.

Nous concluons que les LMT et HT passent par une phase de renouvellement et de transformation sectorielle.

Seconde hypothèse (H2)

Le contexte stratégique de l'innovation dans les LMT des économies avancées sera aussi avancé que son secteur HT (Robertson et Patel, 2007; Mendonca, 2009). Ce niveau devrait être similaire dans les économies en rattrapage mais d'une moindre ampleur.

Nos recherches montrent que le développement interne de la R-D est crucial pour la survie des entreprises, quelle que soit la situation nationale économique ou sectorielle. La production de connaissances grâce à l'interaction accrue au sein des LMT est le facteur le plus important en faveur des économies en rattrapage. En général, les études précédentes ont montré que ce type d'interaction est au cœur du succès des LMT, en raison de sa rentabilité, et de la qualité des connaissances produites par ces interactions entre les différents acteurs du système sectoriel, comme les fournisseurs et les clients. Ces interactions sont toutefois plus significatives que dans les pays avancés à l'égard de la HT. Par conséquent en dehors de la R-D interne, la production de connaissances grâce à des interactions est au cœur du cadre stratégique d'innovation des LMT dans les économies en rattrapage. En plus de la connaissance produite à partir des interactions des entreprises, les économies en phase de rattrapage mettent davantage l'accent sur les connaissances produites par les universités au profit des deux secteurs. Alors que les pays en voie de rattrapage attribuent une attention diversifiée à la fois aux LMT et HT, les économies avancées sont axées sur la HT.

Les LMT dans les deux économies reposent davantage sur une base stable technologique. Ceci est en contraste avec la HT qui bénéficie d'un environnement plus dynamique technologique. Fait intéressant, les économies en phase de rattrapage, perçoivent la production de connaissances comme étant plus dépendante d'une base stable technologique, par rapport aux économies avancées. Cela donne à penser que si les économies avancées sont des innovateurs dans les deux secteurs, les économies en rattrapage sont les imitateurs.

Les fournisseurs jouent un rôle clé dans la HT située dans les économies avancées, par rapport aux LMT dans ces économies avancées. Ceci suggère que tandis que les architectures clés des produits sont encore produites dans les économies avancées, la dépendance à l'égard des fournisseurs extérieurs a probablement augmenté surtout avec la tendance générale vers la modularité du produit. Toutefois, il est essentiel de mentionner que des recherches récentes ont montré que l'industrie automobile chinoise est récemment passée de la partie intégrante de l'architecture à une architecture modulaire quasi-ouverte (Wang, 2008). Suite à cette stratégie, les entreprises achètent des licences ou des copies de pièces génériques et intègrent les différentes composantes en fonction du produit final. Ce résultat suggère que les entreprises dans les économies avancées produisent des produits modulaires, puis les composantes sont sous-traitées aux économies en rattrapage.

En outre, les économies en phase de rattrapage s'appuyent davantage sur l'innovation de procédé, en particulier dans les LMT qui semblent être un secteur de base dans ces pays. La complexité de la demande dans les économies avancées surpasse celle des économies en rattrapage. Ceci explique sans doute que les économies avancées, tout en se concentrant sur les marchés locaux, essayent certainement de pénétrer les marchés étrangers. En outre, les entreprises des économies avancées font face à une demande encore plus complexe qui est satisfaite par l'augmentation de la modularité des produits.

Ce qui est encore plus intéressant est que les start-ups innovantes, dans les économies en rattrapage, profitent d'un niveau plus élevé d'accessibilité des fonds pour développer leurs affaires. Ce résultat est consistent à la fois dans les HT et LMT. Cela montre l'accent qui est mis sur ce secteur dans les économies en rattrapage. Cela confirme le point de vue Gerschenkronien qui stipule que le succès des économies en rattrapage dépent de leur capacité interne à renforcer leur rôle institutionnel et à investir convenablement dans l'éducation, l'innovation et la R-D (Fagerberg & Godinho, 2005).

Le rôle important des institutions, selon le point de vue Gerschenkronien, est clair dans notre analyse. Les économies en rattrapage ne se concentrent pas seulement sur l'éducation, en fait, le cadre réglementaire des institutions de ces économies jouent un rôle clé est évident. Cette importance est évidente dans le cas de la HT dans les économies avancées. D'autre part, les économies en rattrapage renforcement le rôle des institutions en particulier dans le cas des LMT, comme moyen de rattraper le retard. Ce résultat est logique, si les perspectives économiques et technologiques de la LMT sont étudiées. Par exemple, les entreprises de LMT qui sont généralement des experts en exportation, devraient accorder une attention particulière aux approbations réglementaires clés à travers leurs institutions afin de protéger leurs investissements. Dans la même veine, puisque les économies en rattrapage ne peuvent se permettre la dissipation de beaucoup de connaissances, la protection de la propriété intellectuelle est obligatoire pour utiliser correctement et protéger leurs innovations provenant d'investissements en R-D. Ce dispositif institutionnel est soutenu par les gouvernements en particulier dans le cas des LMT dans les économies en rattrapage.

Axée sur les LMT et l'exportation, les institutions des économies en rattrapage jouent un rôle clé dans l'expansion des parts de marché mondiales. Les entreprises peuvent y parvenir en respectant les politiques de réglementation avant la phase de commercialisation. Dans les économies en rattrapage, les institutions de protection de la propriété intellectuelle contribuent à la capture efficace de la valeur des innovations, et de protéger leur propre production pour éviter l'imitation.

Nous pourrions donc en conclure que les gouvernements dans les économies en phase de rattrapage accordent une attention particulière aux LMT. Nos résultats suggèrent cependant que les gouvernements des deux groupes d'ecomomies accordent une attention supplémentaire à la HT.

Les entres des économies en rattrapage perçoivent une croissance sectorielle rapide dans les deux secteurs, plus particulièrement dans les LMT. Les économies avancées ne semblent pas accorder la même attention aux LMT comparativement à la HT. S'il est indéniable que la HT est le principal moteur de croissance, son importance diminue avec le temps. Une explication possible est que le secteur de la HT a peut-être atteint le sommet de sa courbe en S d'innovation technologique, et se stabilise et devient moins turbulent. En revanche, le secteur des LMT, qui est considéré comme l'utilisateur des produits de la HT, a maintenant une gamme de technologies à déployer pour améliorer son processus d'innovation, ajoutant ainsi à la différenciation de son portefeuille de produits. Cela suggère le renouvellement et la transformation d'un 'vieux' secteur perçu comme ayant une croissance très lente. Non seulement la différenciation technologique, offerte par la HT, soutient les entreprises des LMT, elle va aussi de pair avec la stratégie basée sur les coûts.

En raison de la dynamique des éléments ci-dessus et la croissance perçue, les LMT dans les deux économies sont témoins de l'avancement de leur frontière technologique. Par conséquent, cette transformation sectorielle et sa redéfinition sont évidentes. Toutefois, ce renouvellement et cette transformation mettent fortement l'accent sur les LMT des pays en voie de rattrapage, qui semble avoir réussi à attirer le secteur des LMT à l'intérieur de leurs frontiers nationales.

Ces résultats appuient ceux de Robertson et Patel (2007) et Mendonca (2009) dans le cas des économies en phase de rattrapage. Cependant, l'analyse de notre échantillon montre que les économies avancées accordant une attention supplémentaire à la HT au détriment des LMT.

On peut donc conclure que, puisque les HT et LMT sont complémentaires, les économies qui excellent dans l'un des secteurs doivent aussi exceller dans l'autre aussi. Cela est vrai pour les économies en phase de rattrapage, mais ne l'est cependant pas dans le cas des économies avancées.

Troisième hypothèse (H3)

Une approche évolutive utilisant des arbres phylogénétiques est appropriée pour la classification du système d'innovation et pour la reconstruction de l'histoire dans une perspective évolutive.

De l'analyse phylogénétique, on peut voir que les caractéristiques dominantes sont liées aux clients, et la réponse à leurs besoins tenant compte des complexités différentes inhérentes à ces interactions. En outre, les stratégies concernant les coûts et la concurrence, la supériorité technologique et la compréhension générale de la dynamique de l'environnement externe sont les caractéristiques dominantes. Par conséquent, les facteurs mentionnés ci-dessus représentent les caractéristiques les plus stables pour tout l'échantillon étudié. Ces résultats suggèrent deux conclusions importantes. Au niveau sectoriel, les résultats suggèrent que la différenciation de divers facteurs qui caractérisent les HT et LMT n'est pas évidente, comme l'avait antérieurement constaté Malerba (2004).

L'interaction entre les entreprises qui a caractérisé la plupart des LMT (Santamaria *et al.*, 2009; Tsai et Wang, 2009) occupe une position dominante quant à la HT aussi. En outre, le développement des connaissances au sein de l'entreprise est dominante quel que soit le secteur. Cela appuie l'argument selon lequel la capacité d'absorption des entreprises de HT et LMT est bien développé dans les deux, mais probablement pour des raisons différentes. Par exemple, Grimpe et Sofka (2009) ont suggéré que la capacité d'absorption des entreprises des LMT est centrée sur les données de marché, tandis que pour les entreprises de HT elle est axée sur les connaissances technologiques fondamentales et l'expertise. En outre, s'il est principalement avancé que les entreprises des LMT sont plus axées sur les coûts (Von Tunzelmann et Acha, 2005), les entreprises de HT semblent avoir développé une attention récente sur les coûts aussi. L'innovation de procédé, qui est principalement considérée comme une caractéristique principale des entreprises de LMT (Ghosal et Nair-Reichert, 2009; Santamaria *et al.*, 2009; Heidenreich, 2009), est perçue comme une caractéristique dominante des entreprises de HT ainsi. Au niveau national, les résultats de recherche démontrent l'effet de la mondialisation sur les pratiques commerciales, en ce qui concerne les caractéristiques décrites ci-dessus. Par exemple, la complexité croissante des goûts des consommateurs, et de son expansion internationale (Mendoça, 2009) mettrait de la pression sur les entreprises pour se comporter d'une certaine manière unifiée. Les résultats ci-dessus montrent le renouvellement et la transformation des deux secteurs étudiés indépendamment du système national d'innovation dans lequel ils résident.

Lors de l'analyse des mécanismes de production de connaissances, il a été constaté que ce facteur a diminué en importance dans les LMT dans les économies avancées, alors que l'inverse s'est produit dans les économies en rattrapage dans les deux secteurs, ce qui confirme les résultats de Fagerberg et Godinho (2005) de même que de Tsai et Wang (2009). En outre, pour les économies en rattrapage, la perception des entreprises à s'appuyer sur une base technologique stable est essentiellement réduite à néant, en particulier dans le secteur de la LMT. Ceci suggère que le secteur des LMT dans ces économies en rattrapage ne perçoit pas de stabilité des outils de soutien technologique et que ce secteur fasse l'intégration des produits de haute technologie qui sont perçus comme étant dynamiques.

Cela confirme les résultats de Chen (2009) qui étudie l'industrie taïwanaise des outils pour souligner l'importance des fournisseurs de l'industrie LMT, dans les économies en rattrapage (Taiwan). Par conséquent, ce processus de rattrapage pourrait être réalisé non seulement par les moyens officiels d'acquisition de connaissances, mais aussi par des moyens informels qui jouent un rôle essentiel pour les pays dans une situation de rattrapage. La même chose n'est pas vraie pour les économies avancées, où la stabilité est fortement perçue comme importante dans l'économie. Ceci suggère donc que les économies de rattrapage, sont dans une phase de renouvellement et donc perçoivent les possibilités d'une perspective différente en intégrant produits de haute technologie à leur arsenal technologique stable.

En étudiant les facteurs qui influent sur l'innovation, nous nous concentrons sur les trois principaux facteurs de différenciation concernant les approbations réglementaires comme moyen d'obtenir un meilleur cycle de commercialisation, la protection de l'imitation, et la protection de la propriété intellectuelle afin de saisir la valeur de l'innovationNous trouvons que dans les économies avancées, les LMT perdent du terrain, mais qu'elles deviennent de plus en plus significative pour le processus de rattrapage de certains pays. Ce phénomène correspond aux conclusions de Lichtenthaler (2009) qui a comparé l'analyse du portefeuille de brevets entre LMT et HT sur le continent européen. Ses résultats suggèrent que l'agressivité des brevets dans les LMT est limité et que la diversification technologique des entreprises affecte négativement les LMT européennes.

En termes de flux de ressources et de croissance, nous constatons que les gouvernements ont joué un rôle clé dans la construction de secteurs de HT dans les économies avancées. Mais dans les économies en rattrapage l'accent est mis sur les secteurs des LMT. Cette aide gouvernementale est évidente dans les enquêtes sur l'innovation taïwanaise récentes axées sur le secteur des LMT et analysées par Tsai et Wang (2009). Ils ont constaté que le gouvernement taiwanais encourage les instituts de recherche publics à accroître leur capacité de recherche pour stimuler la compétitivité des LMT. En outre, le gouvernement taïwanais exerce des pressions sur les universités pour accroître la collaboration avec des entreprises des LMT, par des moyens de financement, des subventions et par l'établissement de centres de recherche appartenant à l'État (Lee et Wang, 2003). Lichtenthaler (2009) propose d'augmenter le rôle des pouvoirs publics dans les économies avancées dans le secteur LMT afin d'accroître la qualité des brevets : un élément obligatoire pour augmenter la performances des entreprises dans le secteur des LMT (Ernst, 2001; Shane, 2001).

Cela met en évidence que la promotion de ces secteurs est une priorité pour le processus de rattrapage notamment dans les LMT. La facilité d'obtention de fonds de démarrage est dominante dans les économies avancées par rapport aux économies en rattrapage. Toutefois, pour les LMT dans les économies en rattrapage, l'appui gouvernemental et la facilité d'obtention de fonds de démarrage sont mutuellement exclusifs. Ceci suggère la mise en place d'une coordination fine entre le gouvernement et les different agents du système national d'innovation.

L'examen des résultats de croissance des ventes montre que les économies avancées mettent l'accent sur la HT, tandis que les économies en rattrapage se concentrent sur les LMT. Alors que la course pourrait sembler équilibrée quant à la croissance des ventes dans les niches récemment ouvertes, nos recherches démontrent que les pays en rattrapage commencent à mettre un accent supplémentaire sur la HT aussi. Ce n'est pas vrai pour les économies avancées qui semblent avoir renoncé aux LMT pour la HT, laissant les LMT au économies en rattrapage.

Ces résultats vérifient les hypothèses H1 et H2, de même que H3. Nous concluons que l'approche par arbre phylogénétique pour classer les entreprises dans les systèmes d'innovation (secteurs HT et LMT, pays avancés et en rattrapage) est appropriée et a permis de constater l'évolution des meilleures pratiques au sein de ces systèmes. Cette conclusion générale de la recherche suggère que les HT et LMT traversent une phase de transformation et de renouvellement. L'un des principaux moteurs du renouvellement et de la transformation est l'émergence des économies en rattrapage qui portent attention à tous les secteurs industriels, toutefois, avec un fort accent sur la LMT. Ce résultat a été vérifié statistiquement et en utilisant l'analyse évolutive par arbres phylogénétique.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

FDT	Food, Drink and Tobacco
GPT	General Purpose Technology
HT	High Technology
ICP	Internet Content Provider
ICT	Information and Communication Technology
ISP	Internet Service Provider
ITL	Inward Technology Licensing
LMT	Low, Medium Technology
M&A	Merger and Acquisition
NSI	National System of Innovation
R&D	Research and Development
SI	System of Innovation
SSI	Sectoral System of Innovation

INTRODUCTION

In the past decade, the innovation literature has dedicated a special attention to the High Technology (HT) sector. Such an attention was primarily due to the critical role high techs play to foster economic growth, building new economies, and enhancing the well being of societies. This increasing attention has pushed a considerable part of the innovation literature from the traditional Low, Medium Technology (LMT) sectors (such as the textile, food, and others) towards high tech sectors (including biotechnologies, telecommunication, and others).

This deviation in the literature has caught the eye of innovation scholars who are currently highlighting the important role that LMT plays to increase economic growth and manage the currently increasing unemployment rates. This attempt to increase the awareness of the academic, industrial and financial sectors to the importance LMT cannot be isolated from the national system of innovation in which those sectors are positioned. Adding a supranational dimension, it is witnessed that a considerable proportion of LMT activities are currently migrating from developed to developing economies.

From the above, one might imagine that the deviation in innovation literature from LMT to HT was merely on the academic level. On the contrary, this focus on HT from leading economies has been accompanied by a sectoral migration of LMT towards catching-up economies, or from highly industrialized to newly industrialized economies as Robertson et al. (2009) coined it. In the same vein, Robertson and Patel (2007) observed that developed economies excelling in HT sectors, most likely hold a higher innovative performance in LMT sectors. This finding has been also supported by Mendonca (2009). The findings of Robertson and Patel (2007), Robertson et al. (2009) and Mendonca (2009) will be the prime motivation of this research work.

If we were to study this kind of interplay between national and sectoral systems of innovation, the time dimension becomes crucial to study. The work of Bruland and Mowery's (2005) investigates innovation through time. Consequently, adding the time dimension, a better understanding of the current sectoral and national systems of innovation is achieved. Three main industrial revolutions shaped the current industrial theme:- the first, second and third industrial revolutions.

The First Industrial Revolution

Time and history are of high importance when studying innovation. (Bruland and Mowery, 2005).The first industrial revolution was ignited by steam Power, the second revolution by electricity, and the third by ICT. From an innovation perspective, historical change is examined in light of changes that occur on the economic activity level, institutional roles, and changes in the knowledge generation patterns. This evolutionary perspective would be a sound hypothesis for the evolutionary theory presented in this research work.

Pomeranz (2000) raised a question on the reason why northern Europe managed to foster its innovation throughput, while the rest of the world did not, being on equal foot in the eighteenth century. Pomeranz refers this to “The acquisition by the major European powers of colonies as markets for manufactures and sources of food and raw material, and the development within Europe of coal as a new energy source” (Bruland and Mowery, pp 351). Another dimension, laid by Braudel (1984), Wallerstein (1974), and Landes (1998) relates the phenomena to the emergence of property rights as a stimulant for innovation. This result is supported by MacLeod (1988) who found that patenting activities grew remarkably after 1750 in capital goods directed to consumer markets (Berg, 1998; Sullivan, 1990) despite the financial and logistic issues associated with it. Therefore at this epoch, one could claim that technological change was a prime characteristic of the first industrial revolution. It is important to remember that these industries, textiles and furniture, were the HT of their time and are now considered as LT (Bruland and Mowery, 2005)

Another dimension is the political institutional change; defenders of this theory assign the need for innovation, when political rulers are weakened. The theory is considerably criticized. Innovation existed in multiple industries, such as textile, glass, steam power and agricultural sectors. However, textile and steam power have a higher weight, with respect to the industrial revolution, comparatively with other sectors. If we were to put innovation pattern in the context of the first industrial revolution, it should be emphasized that is mainly realized on individual inventors despite the apparent diffusion of scientific ideas that had almost no production with the exception of the glass making industry (Bruland and Mowery, 2005). This is recognized to be guilds. Codification of knowledge was still embryonic at the beginning of the industrial enlightenment at the beginning of the eighteenth century. This has changed into more codification resulting into technical manuals and books in the late eighteenth, and beginnings of the nineteenth century. Two factors mainly shaped the institutional change characterizing the first industrial revolution. The first factor is the organization forms. The second is the managerial control of production. As for the first factor, newer organizational forms allowed joint stock associations, and hence small family based, guild oriented firms transformed into larger ones with a wider scope, and more enlarged production scale. The second is the Taylorizm and its accompanying managerial component that produced the first organized work force. Consequently, better managerial calibers where chosen to run entrepreneurial based plants. This could be argued to lay the foundation of the second industrial revolution.

The first industrial revolution included industries such as iron, steel, coal, textiles, and mechanical engineering. The revolution was led by Britain/UK.

The Second Industrial Revolution

The second industrial revolution, started in Germany, France, and later in the US, by shifting from the traditional industries developed during the first industrial revolution, to include new industries such as chemicals, optics, and electricity (Bruland and Mowery, 2005). During this era, formal ties between universities developing formal and basic science, and the industry became stronger. This tightening relation was manifested by: a) formal training of potential inventor (engineers) took place, while the role of individual inventors diminished; b) the role of external institutions performing the formal education\training increased; c) internal, firm knowledge production mechanisms became more powerful especially with the increasing size of the firms (Bruland and Mowery, 2005). As a result, the main leader firms, who maintained the momentum for the second industrial revolution, are large scale, vertically integrated enterprises, whose corporate main strategic directive was focused on technological/industrial innovation, leading the second Schumpeterian Mark of creative destruction (Bruland and Mowery, 2005).

Time is needed in order to link scientific discoveries (inventions) to technological innovations (innovation). This time for commercialization is due to the lack of manufacturing technologies that lagged bringing the invention to market. A good example is Faraday’s invention of electromagnetism that began to be commercialized into electrical products during the second industrial revolution (Bruland and Mowery, 2005).

The origins of industrial research started in Germany, and were later mimicked in the US in the beginning of the twentieth century. The first in-house industrial R&D labs in Germany, where established by German firms seeking to commercialize chemical inventions. The role of universities increased in Germany starting from the 1920s, performing several industry-serving roles by training engineers and working on R&D project with the industry. The contrast with UK universities is obvious, a phenomena that explains the leadership of Germany and the US in the second industrial revolution, and Britain's lag.

This German national innovation system in the 19th century was the prime factor for the emergence of new, early entrants who mastered new technologies in electricity, and chemical products. Examples of these firms are Siemens, Bayer in Germany and DuPont in the US. Those firms strengthened their ties with government and university labs. Additionally, these firms were the first practical users of the national patent system used to appropriate their inventions. This rise of firms power at the beginning of the 20th century, led a wave of creative destruction. This corporate R&D lab mechanism, has transformed the role of manufacturing firms from a secondary role (where the primary was the main inventor), to a deterministic role, thus reducing the role individual inventors played in the first industrial revolution (Bruland and Mowery, 2005). Not only did these large enterprises concerned with developing highly advanced in-house products, those firms additionally scanned the market for new technologies build by new entrants, for acquisition. The technological change in the US industry was shaped by the accelerated growth of the US market, large scale continuous process production, and finally the Oil and Gas industry that resulted from increasing demand on the automobiles and internal combustion engines (Bruland and Mowery, 2005).

The Third Industrial Revolution (After 1945)

After the war, the most important preoccupation of the US government is safety, defense and health. This era is characterized by an increased weight for governmental spending to foster R&D. Consequently, the US government has focused its governmental funding to R&D especially to small firms, in different domains, together with pumping additional funds in the defense sector, that in turned influenced high-tech sectors. As a result, new firms in the computer, semi conductors industry managed to grow, and reach an incumbent position. This are witnessed the highest collaboration efforts between industry and universities. “The relatively weak formal protection for intellectual property during the 1945-1980 paradoxically aided the early growth of new firms" (Bruland and Mowery, 2005, pp. 367).

To conclude, the first most important trait, of innovation through time, is the innovation systems that influenced the development of knowledge repositories and innovation. The first industrial revolution was mainly relying on craft oriented, trial and error process, together with a prime institutional change. The second industrial revolution witnessed the development of large enterprises, and what is so called the age of creative destruction, with a light influence from the governments. The third industrial revolution was mainly based on governmental funding, to fund high technology sectors, together with an increased collaboration between different institutions and agents (Bruland and Mowery, 2005). Each of these revolutions were also nationally bounded, for instance the first industrial revolution occurred in UK, the second, in Germany and later US, and the third, in the US. Therefore, the above brief introduction of the three industrial revolutions based on Bruland and Mowery (2005), has demonstrated this kind of interplay between the national and sectoral systems of innovations, while adding the time dimension manifested in the three industrial revolutions.

On the national level, the catching up process becomes important, since it does not only capture the national systems of innovation, but also it adds the dynamics of the catching up process.
According to Fagerberg and Godinho (2005), the catching up literature includes three important views: the first is that of Thorstein Veblen and Alexander Gerchenkron who analyze the catching up of Germany towards the UK and the role of institutions to realize the process; the second is the literature of Asian (including Taiwan, South Korea and others) catching up towards the Japanese way; finally the third relates to the role of technology and innovation resulting in long run economic growth.

European history is central to the understanding of the catching up phenomena. Veblen (1915) was the first to realize that "recent technological changes altered the conditions for industrialization in latecomer economies" (Fagerberg and Godinho, 2005, p.516). At the beginning of the industrial revolution, knowledge was tacitly embedded in skilled workers, and hence knowledge transfer was the result of these workers' mobility. However, with the recent advances in the codification of knowledge, latecomers can actually take the full benefit from the technology without contributing any cost to its development. Veblen predicted this catching up phenomenon for other countries such as France, Russia, Italy and Japan. Alexander Gerchenkron (1962) did not share the same opinion as Veblen (1915). Gerchenkron argued that Veblen's view of the catching up phenomenon was based on the case of UK and Germany. This form of industrialization that Britain witnessed at that time was actually small scale and fitted Veblen's view, which did not include the important role of institutions. Therefore, according to Gerchenkron, to succeed, catching ups should develop separate institutional instruments that are uniquely distinguishable from that of leading economies. Consequently, Gerchenkron attributed the successful catch-up to the role of banks, governments or private organizations in the industrialization process (Fagerberg and Godinho, 2005).

More literature explaining the catching up phenomenon of the Asian countries post WWII followed either Veblen or Gerchenkron views. However, most researchers (Shin,1996; Wade, 1990) would agree that Asian catch-up strategies were much aligned to Gerchenkron's views. Gerchenkron's view on the role of banks together with governmental support to promote catching up is evident in post WWII Japan (Fagerberg and Godinho, 2005). The role of banks and governmental support grew, compared to the private investors and family ownership that prevailed before the war. With time, the role of the state decreased, and the Japanese banking system was solid enough to sustain the industrial catching up. Furthermore, the Japanese case highlighted the role of process innovation in the catching up process. As such, the Japanese case was a leading example for other catching up economies in Asia such as South Korea and Taiwan (Fagerberg and Godinho, 2005).

On the macro view, according to Fagerberg and Godinho (2005, p. 524), Abramovitz (1986 & 1994) explains the discrepancies between countries performances by "congruence and social capability". The first concept is basically how national systems are different from, or similar to, each other in terms of various economic characteristics such as factor supply and market size. The second concept includes various factors such as the education level and the levels of investment in R&D as well as the role of the financial system to mobilize resources (Fagerberg and Godinho, 2005).

Based on the above, this research work therefore targets to analyze the Sectoral and National systems of innovation from two angles. The first is a comparative approach; the second is an evolutionary one. The purpose behind using the comparative approach is to further enhance our understanding of the sectoral and national systems of innovation. The purpose behind using an evolutionary approach is to add the time dimension important to explain the current national and sectoral systems of innovations.

In order to carry out the analyses, the theoretical framework for that research work will be based on the pioneering work of Malerba (2004), when analyzing the sectoral systems of innovation. This systematic approach includes organizational, institutional, political, social and economic factors. Consequently, when studying innovation from an SI perspective, these various interacting factors ought to be considered, in order to properly understand the innovation phenomena. In that framework, organizations could be other firms (such as suppliers, competitors, customers, etc.) or non-firm entities such as universities and governmental institutes (Edquist, 2005). The national system includes two groups: the leading and catching up economies.

Malerba (2004) sectoral system of innovation is mainly composed of three entities: knowledge and technologies, actors and networks, and institutions. First, *knowledge and technologies* represent the sectoral knowledge base, technologies and inputs, and are responsible of the sector's boundaries. This is why its box leads to dynamics and growth patterns that influence the sector's evolution and transformation. Second, *actors and networks* simply represent the various organizational entities involved in the innovation process such as firms and financial organizations, or non-organizational entities such as universities. The customers that can take various forms of organizational structures are the demand creators, and are a fundamental part of the sectoral system of innovation. Using a knowledge-based view of the innovation process, the different entities are all interconnected by arrows. Third, *institutions* are basically the bodies responsible of norms and routines, such as public funding institutions, regulation and standards institutes. Such institutions have both sectoral and national roles.

The representation of our theoretical framework not only follows Malerba's (2004) view of an SSI, it also takes into consideration Freeman's (1987) structure representing the network of institutions, and their interactions. These interactions will generate the learning process, a phenomena that is heavily supported by Lundvall (1992). Due to the dynamic nature of the interactions and of learning, sectors go through various dynamic and growth patterns that result.

The objective of this research work is therefore to capture the main differences between the HT and LMT, and test whether the sectors are undergoing any transformation or renewal processes. Second is to introduce the national systems of innovation, to test if the recently reported sectoral migration is occurring and what governs the differences between the leading and catching up economies. The third and final is to capture the evolution of those systems of innovations and test if they match the findings of the first and second hypothesis. As explained, Malerba (2004) will be main theoretical framework. The Managing Innovation in the New Economy (MINE) data addressing the firm's context of innovation in its own sectoral perfectly fits the problematic and is based on Malerba's (2004) theoretical framework. This data however is cross-sectional, hence, lacking the time dimension. In order to create the time dimension, and study the evolution of the sectors/economies, each firm's input is considered as a DNA. Consequently, each firm's record will be considered as its respondent perception of best practices used in his/her own sector and economy. I will coin them in that case: perception memes. Where memes' are the cultural unit subject to evolution as Richard Dawkin's coined it. Using the phylogenetic trees concept and the parsimony methodology the time dimension is created, and the comparative approach complemented.

The rest of the dissertation is organized as follows: Chapter 1 presents the literature review relevant to the thesis; it addresses HT and LMT, leading and catching up economies literature. Chapter 2 addresses the methodology, data description and sequence of the chapters, with respect to the major research hypotheses. Chapters 3,4 and 5 address the major three research hypotheses. Chapters 3 and 4 will address the sectors, and economies from a comparative stand. Chapter 5 will address the problem of evolution using a phylogenetic tree analysis and creating the time dimension. Chapter 6 presents a general discussion, and finally a conclusion is presented.

Chapitre 1 LITERATURE REVIEW

The literature review will mainly target three axes. The first targets HT and LMT. The second targets leading vs. Catching-up economies. The third is the evolution of national and sectoral systems of innovations.

1.1 High Tech (HT) and Low Medium Tech (LMT)

High technology sectors do not emerge by chance. Rather, higher tech sectors could be considered as the sectors most targeted for growth. As a result, such sectors change their nature and transform with time from high tech to low and medium techs. As we will see later from the evolution of industrial sectors, each industrial breakthrough was considered revolutionary with respect to its precedent. For instance, iron, mechanical and textile technologies are the prime innovative technologies of the first industrial revolution that emerged as a result of steam power technologies in the United Kingdom (UK). Such technologies\sectors were considered the high techs at the time of the first industrial revolution, and were later replaced by other technologies that became the focus of industrial policy. In the second industrial revolution, electricity was the key General Purpose Technology (GPT) (Helpman, 1998) that led the development of other important sectors such as automobiles, optics and chemicals. The same phenomenon happened after the emergence of the information and communication technologies (ICT) sector that became the high tech of its time at the beginning of the 1980s.

Recent Literature on Low Medium Techs and High Techs

Up until this moment, LMT is regarded as a lagging sector in terms of growth. This currently dominant view does not represent equivalently the weight of those industries on the global level. For instance, OECD (2003) reports that more than 32% of the global manufacturing exports are of Low Tech (LT) products (Mendonca, 2009). Chen (2009) reports that according to Lie and Brookfield (2000), in 1969, the total production of machine tools worldwide was worth 9M$, this figure has multiplied to reach 3.7B$ according to Gardner Publications (2007). These interesting figures drive us to further analyze the currently labeled LMT. In such lagging sectors, cost is often the main preoccupation of firms. In contrast, HT firms, targeting higher returns of investment on their R&D intensive process follow more of a differentiation strategy (Viardot, 2004). However, with the rising price competition in lower tech sectors, firms started to add a considerable differentiation strategy to their original ones (Von Tunzelmann and Acha, 2005). Additionally, LMT firms are process innovation oriented (Ghosal and Nair-Reichert, 2009; Santamaria et al., 2009; Heidenreich, 2009). The considerable lump sum of HT firms is contrarily to LMT, product innovation driven.

Recent studies demonstrated the importance of LMT sector and the role they play in the modern industrialized economies. For instance, Kirner et al. (2009) demonstrated that the Low tech excelled in process innovation, while lagged into product innovation compared to the HT. Hauknes and Knell (2009) showed that knowledge flows from HT to LMT sectors. However, they find that this flow is not compared to the flow generated into science based industries. In their findings, they find that science based industries are far more dependent on in house R&D. Using the European community innovation survey (CIS4) and the European Union (EU) regional data to explore the main characterstics of the LMT industry, Heidenreich (2009) finds that the LMT industry is more dependent on process innovation. Also he finds that firms in the LMT highly depends on non formal R&D sources of knowledge such as patents, training, etc. In terms of concentration he finds that the LMT industry provides poor growth, if compared to the highly concentrated services counterpart. Furthermore, Grimpe and Sofka (2009) performed a comparative analysis to thirteen European countries using the third European community innovation survey (CIS3). In their research, they investigated the various sources of knowledge that firms target when searching for innovative knowledge. On the one hand, They found that Low and Medium Low firms will seek to search for knowledge within customers and competitors boundaries. On the other hand, they found that Medium High and High Tech firms will concentrate on suppliers and universities.

Santamaria et al. (2009) addressed the importance of Advanced Manufacturing Technologies (AMT), training and design to produce innovations. They also address multiple other sources of knowledge such as alliances, consulting services, and joint ventures. They found that design and training are the principle sources of knwoeldge to produce product innovations in the LMT sector, opposite to the HT. However it was found in the case of process innovation that design is more important in the case of HT, than in the case of LMT.

Tsai and Wang (2009) investigated the relationship between knowledge acquisition and adaptation in the Taiwanese LMT sector. In their analysis they used the Taiwanese innovation survey, and addressed two major axis: the first is external market based acquisition, and the second is collaboration with competition, suppliers and customers. They found that Inward Technology Licensing (ITL) does not significantly contribute to the Taiwanese LMT innovation performance. They referred this to the difficulty of integration between old and new technologies. Furthermore, R&D outsourcing could be problematic due to knowledge leaks. Knowledge collaboration seems to be the best methodologies for knowledge acquisition in the Taiwanese LMT industry. Tsain and Wang (2009) found that the more firms in the LMT hold a greater absorptive capacity, the more they benefit from collaboration to acquire knowledge.

Chen (2009) finds that SMEs in the Taiwanese machine tools industry make an efficient use of international events and exhibitions to learn from competition and further adapt their products. Furthermore, he emphasized the role of engineers to foster technological and knowledge transfer. Therefore, Engineers in that industry are prime agents of technological change. While Chen (2009) focused on SMEs, Ghosal and Nair-Reichert (2009) investigated large firms in the global paper industry. They found that investment in the mechanical technology and measurement technologies has a considerable impact on the pay off of that industry. Furthermore, learning by doing is a prime methodology for the global pulp and paper industry. Lichtenthaler (2009) addresses corporate strategies and patent portfolio in the High, Medium and Low tech industries. For his analysis he uses 136 European firms data to analyze technological aggressiveness and diversification, patent size and quality. He finds that Medium Tech firms gain less from aggressive strategies than HT, and that they Lower tech firms depend highly on open innovation due to their lack of commitment to R&D.

Firm’s absorptive capacity is its ability to identify, activate and generally manage knowledge for the firm’s success (Cohen and Levinthal, 1990). Absorptive capacity can therefore be tuned to seek knowledge about market input, or deep technological knowledge. Classifying HT would as a priority focus on an absorptive capacity targeted on deep technical knowledge, while LMT would be primarily focused on the market input side (Grimpe and Sofka, 2009). When studying the Taiwanese machine tools industry, Chen (2009) found that trained engineers are the main element of absorptive capacity with respect to LMT firms.

Technologies could be either developed or acquired. Technology acquisition could take various forms: using Mergers and Acquisitions (M&As), licensing contracts (Inward Technology

Licensing or ITL), or formal and informal cooperative R&D strategies (Tsai and Wand, 2009). Technology licensing enables the firm to lower its cost of production, by primarily focusing on its core competitive technologies and licensing others externally. One downside of adopting ITL, is that firms would be supplier dependent, eroding their competitive advantage on the licensed products. Tsai and Wang (2009) found that ITL does not contribute positively to firm's performance in LMT. They referred this to the lack of integration capabilities between old and new technologies. This issue is primarily due to the lack of an adequate absorptive capacity. Accordingly, the authors advise the development of the proper internal R&D structure, to enhance the absorptive capacity and hence, increase the efficiency of external technology acquisitions.

It is imperative to understand the dependency between the two sectors, where LMT is a prime user of HT (Robertson and Patel, 2007). This interdependent relationship puts the two sectors into a complementary position rather than a competitive one. Furthermore, an increase of technology adoption by LMT develops into higher diffusion rates of HT innovations. Adapting HT products added to the LMT capacity to compete on design, functionality and quality (Santamaria et al., 2009). This power of controlling the demand that LMT holds, did not refrain the sector from patenting activities. On the contrary, Mendonca (2009) found that the Food, Drink and Tobacco sector (FDT) is witnessing an unprecedented growth in patenting activities. Mendonca refers attributes this to the increasingly sophisticated tastes motivated by international expansion. While the quantity of LMT patenting activities has been increasing, quality of LMT patent activities is still lower than that that of the HT (Lichtenthaler, 2009). It is still however found that knowledge acquired by patenting activities is still marginal, in the case of the paper industry (Ghosal and Nair-Reichert, 2009). This is probably due to the continuing dependency of the LMT sector on learning by using (Lundvall, 1988), learning by interacting, by producing and searching (Lundvall, and Johnson, 1994) found by Chen (2009). This finding supports that of Santamaria et al. (2009) and Tsai and Wang (2009) confirming that the primary source of knowledge for the LMT sector is based on the collaborating with customers and suppliers.

Chesbrough's (2003) open innovation model emphasizes the role of external actor to enhance firms' innovation performance. While LMT is primarily dependent on collaboration with suppliers to enhance its innovative capacity, the sector increased its competence by the constant exposure to the increasing complexity of users demand. This supplier highly influential role in the LMT has been highlighted by Chen (2009) and Heidenreich (2009).

From this short survey of the three revolutions presented in the introduction, and the current status of HT and LMT, it is seen that the trajectory of development of the high tech sectors, and the stability of lower tech sectors cannot be the breed of the moment. Rather, those high techs were the result of various factors that facilitated their development, compared to lower techs that lost their attractiveness due to their lower return on investment, and their inability to generate wealth or foster the required economic growth. Added to the sectoral systems of innovation factors, the role of nations with respect to those sectoral dynamics is quite evident. Governments play a key role towards the development of certain sectors, a result that is very clear in the case of the US with respect to the third industrial revolution. Currently, those dynamics occur under the form of migration of LMT activities from developed to developing economies (Robertson et al., 2009). This nationwide segmentation, and the role they played into the emergence of the industrial revolution historically, proposes a leading and catching-up categorization with respect to systems of innovation.

1.2 Leading and Catching up Economies

The catching up process is “the ability of a country to narrow the gab in productivity and income vis-à-vis a leader country” (Fagerberg and Godinho, 2005 p.514). As seen from our analysis to industrial revolutions, at the nineteenth century the United Kingdom is classified as the leader, will the United States and Germany were in a catching-up position. Later the United States took the lead while others took the followers position. This was established by coming up with new ways of organizing production and distribution, thus through innovation (Freeman and Soete, 1997; Freeman and Louca, 2001). When analyzing 21 OECD economies from 1960 to 2005, Schaik and Van de Klundert (2010) discovered that the catching up process could be subdivided into two identifiable periods of technological change. The first is imitation, followed by the second, based on innovation.

In 2007, the Society of Manufacturing Engineering (SME) reported in 2007 that the US is still in a leading position, however those other nations are aggressively catching up. The main reason based on which the catching up process will be at its peak is the growing middle class demand emerging from non-industrialized economies. Moreover, the role of China in the international arena, demonstrates its attractiveness for offshore R&D activities. This ability of the Chinese sectors to adjust according to demand is recently supported by Xie and Zedtwitz (2010).

One of the pioneering works aiming to understand the catching up process has been presented by Alexander Gerchenkron (1962). Gerchenkron has found that for the catching up process to succeed, they should develop distinguished institutional instruments. For instance some models of the catching up process propose a balanced mix between international borrowing and domestic savings to enhance the catching up process (Bellone, 2008). This highlights the crucial role of financial and governmental organizations in the industrialization process (Fagerberg, and Godinho, 2005). Shin (1996) and Wade (1990) followed Gerchenkron's view when studying the catching up process of the Asian economies in the post World War II era.

While various economies are in a catching up process, we can expect that each country policy formulation within that group will differ according to the characteristics of its own economy. For instance Wang (2007) found that South Korea pursued a Schumpeterian scale-based technological development. In contrast, Taiwan use a neo-Marshallian network based technological development. Some of catching up economies was under a social regime. Those social regimes, for instance in the Former Soviet Union (FSU), Central and Eastern Europe experienced economic growth in the periods of 1925-75, and 1945-80, respectively (Gomulka, 2010). Starting the 1980s, this growth was later opposed by a stagnation period, especially after shifting towards market-based economies. This economic transition from a tightened government control towards free market orientation necessitated heavy governmental support, through well-established governmental institutions.

This governmental role in the catching process has been witnessed in various catching-up economies such as South Korea, Singapore and Taiwan (Tu and Yang, 2008). For instance Lofgren and Hsieh (2009) studied the three economies biopharmaceutical innovation and industrial development. They found that catching up governments encouraged public investment in basic research. Moreover, those governments utilized various influential industrial policies to promote the industry. It includes public investment in biomedical hubs and R&D tax credits. Furthermore, the role of universities in the catching up process is not only limited to the pure academic\scientific contributions but additionally by establishing effective integration of academic institutions into the industrial development phase (Mazzoleni, 2008).

On the product architecture level, catching up economies are currently experiencing what is labeled the ‘Quasi Open Modular Architecture’. This type of architecture has been witnessed by Wang (2008) in the Chinese automobile industry. This architecture consists of licensing parts that can fit various products or architectures, hence achieving a low cost competitive strategy.

When analyzing the video compact disk in China, Xie and Zedtwitz (2010) found four important factors that affect the catching up process. First, local demand plays a key role into shaping innovation strategies. Second, the innovating firm in a catching up economy cannot isolate itself from the leading economies suppliers. Third, is the important role of inter-firm alliances to produce advanced technological innovations. Fourth and final, is the integration capacity of the follower to mix and match various technologies, with a competitive scheme of pricing.

This complementary role between developed and developing economies, influence positively the quality of the final products produced. This kind of trading patterns is also responsible for the diffusion of knowledge between leading and catching ups. This result has been found by Cavallaro and Mulino (2008) when studying the trade between Central, Eastern European countries with their European Union (EU) partner. Moreover, in order to apply such factors firms’ flexibility to adapt to market conditions through an enhanced absorptive capacity is mandatory. This flexibility enables firms in the catching up economies to compensate for their latecomer position. This is supported by the findings of Li and Kozhikode (2008) when studying the Chinese mobile phone industry.

The above factors should not marginalize the innovative capacity of domestic firms in the catching up process. When studying the Chinese telecommunication equipment industry, in the period of 1980 to 2002, Fan (2006) found that the innovation capability of firms was the prime success factor of the catching up process. Fan’s research suggests that in house R&D development as a priority, supplemented with external alliances is essential for a successful catch up.

Generally, If we were to examine the catching up process, it is important to mention the Asian experience, specifically that of Japan. After the Second World War, Japan underwent various structural changes. The role of government and bureaucratic intervention was very important in the early phases of the catching up process. (Fagerberg and Godinho, 2005). This intervention was represented into activist economic and a protectionism trade policy. In that restructuring, old industries were phased out in favor of more progressive industries. In that a variety of strategies were used including a combination of economies of scale, adapting to the growing demand, product differentiation, as well as increasing the learning mechanisms. The fruits of such a strategy were manifested in the steel industry, ship building, car manufacturing and consumer electronics. While there are some evidences of product innovation, process innovation dominated the Japanese Catching up process, specially the organizational types that enabled the implementation of scale economies, efficient inventory management, a superior quality products. (Fagerberg, and Godinho, 2005).

The Japanese catching up process was a role model for other Asian economies such as South Korea, Taiwan and Singapore (Fagerberg and Godinho, 2005). Al these countries, underwent strict industrial structural changes led by catching up economies governments. For instance, South Korea, and Taiwan pushed highly intervened policies to protect local industry such as tariff protection, financial support, and product quantitative restrictions. While addressing export, catching ups ha recently emphasized policies that support R&D and Innovation. This does not eliminate the specifities of such economies. For instance, South Korea still highly depends on family owned groups, versus Singapore that mainly depends on foreign multinationals. Taiwan's industrial structure, on the other hand, is dominated with private SMEs (Fagerberg and Godinho, 2005)

While the Japanese catching up was self financed, that of South Korea depended extensively on foreign lending. Assuming more debt, the South Korean economy was vulnerable to the end of the 1990s financial crisis. This highlights the important role that institutions and policies play in order to shape the catching up process. (Fagerberg and Godinho, 2005)

1.3 Systems of Innovations and Evolution

Evolution is about changes that occur with time. If evolution of systems of innovation is taken as a framework, it is important therefore to highlight the changes that occur with time, with respect to those systems of innovations. Sectors with their productions of technologies are the resultant of industrial revolutions. These revolutions, with their radical technology production are also coined the 'high tech' of its time. For instance, Chandler (1962) when studying the American enterprises, argued that year 1850 is quite remarkable as the beginning of the development of the US railways, an event that is impartial toward the flourishing of the US industrial revolution (Mokyr, 2000). This finding combines three important elements: time, transportation on the sectoral level, and the United States on the national systems of innovation level. Such interplay between systems of innovation and time is therefore essential if following an evolutionary approach. This form of integration of historical evidence with a broader conceptual framework in the field of innovation, is a task that (Bruland and Mowery, 2005) foresaw as very important for future research.

From the above, we can witness the interplay between systems of innovation, time and industrial revolutions. In order to use an evolutionary model of change, we need to conceptualize a general understanding of technology. In this, technology will be viewed in the form of practice and knowledge. Practice and knowledge are two main components that fit evolution, since both are subject to incremental changes with time, and are subject to variation and selection. Such a conceptualization will enable us transform the questionnaire information to knowledge and practices cultural units. In what follows, I will address technology, technology and practice, knowledge, and technology as practice and knowledge in the same order.

Technology

Technology is not that isolated from culture and sectoral and national boundaries. For instance, technological change is a critical component of cultural evolution where behavior is the result of Darwinian biological evolution (Mokyr, 2000). If we isolate technology from cultural aspects, it often misses the Darwinian interpretations since the evolution of technology is quite rapid by nature (Mokyr, 2000). When studying economic change however, the evolving culture of technology is an important aspect of the accumulation of complex knowledge (Cordes, 2005).

Furthermore, such an isolation of technology from cultural aspects would minimize the role that technology plays as an expression of varied human purposes or wants (Cordes, 2005).

In a cultural, socio-economic context, technology provides “strong guidance regarding how to improve practice” (Nelson, 2000, pp 68). Technological evolution could therefore introduce new ways of doing that lead towards significant improvements to new business practices (Nelson, 2000). Consequently, this will enable us understand, how best practices evolve, facing technological change. For instance, when trying to explain technological evolution, Nelson (2000) mentioned the case of the American automobile companies, who suffered to understand how their Japanese counterparts operate (Nelson, 2000). This example includes both sectoral and national systems of innovations arguments.

Nelson (2000) classified technological evolution into four schools of thought. The first is the evolutionary epistemology led by Donald Campbell (1974) who studied knowledge evolution. This school seeks a better fit between understanding and reality. Technological variation occurs blindly and selection is the prime factor to be considered when studying technological evolution. The second group includes historians of technology who, starting from an interest in technological change, as opposed to the epistemology group that starts with the evolution of knowledge, then study the evolution of technology as part of a knowledge-centered interest. Competition shapes technological selection, hence, among the various technologies solving problems, the best is selected. Technologies are therefore always improving. Technology historians see technologists’ judgments as agents for the users. Third, sociologists often see that technology is evolving and that a community is involved in the selection process; however the communities’ definition is often broad. They often see needs based on a political process, with a bandwagon characteristic. In the social context, Social Constructivism in Technology (SCOT) argues that all technology is socially constructed, and consequently it reflects a certain groups interest rather any technical or economic criteria (Constant, 2000). The fourth is composed of the economists who study how technology fits user needs, and that this market is the main community for the study of technology (Nelson, 2000). This research work is positioned between the first and second group of scholars.

Technology as Practice

In the previous session, we have asserted that technology cannot be isolated from its cultural and socio-economic boundaries. In this section, we will get more abstract seeing technology as practice. Firms exist to develop technological products through its production processes (Mokyr, 2000). Members of the firm in the past, often members of the same family – jointly carry the technique of production. Each time the firm produces the goods it specializes in; it acts as the vehicle of that technique. Even though this guild structure has changed since the industrial age when control and ownership were separated, the model is however still valid with a varying structure. Furthermore, we can additionally think of technology not only as a technique is not only a vehicle, but also an interactive structure with the environment (Mokyr, 2000).

This leads us to see technology as "practice and understanding" (Nelson, 2000). Practice is actually the selection process, and understanding represents how users understand the technology and the community of technologists. Therefore, while in general the understanding could be unified, the selection process as a practice could be different (Nelson, 2000). Therefore, what evolves in technology is information not artifacts (Fleck, 2000 Ch 18). Since what matters for evolution are ancestor-descendent lineages, technological change could therefore be interpreted in terms of combinations of cultural units (meme) (Constant, 2000). In that context, the selection of information occurs in technology through the social process embodied in recursive practice (Constant, 2000). This recursive (could be business, engineering, financial or juridical) practice yields reliable and valid knowledge, and with time, the product of knowledge and practice gets better (Constant, 2000). Following this line of thought, smaller steps of business practices lead to radical breakthroughs. Consequently, even breakthroughs can be viewed as incremental innovations. This way, evolution is justified (Constant, 2000, pp. 224). "Recursive practice is then highly effective process in technology". What evolves in technology is information and reliable knowledge. Consequently what really matters is inheritance. As a result, technology evolution is about descent and the various modification techniques. Recursion in technological practice, leads to increasingly reliable and valid knowledge (Constant, 2000).

When thinking about practice, however, we should discount the rationale behind the practice. Rationale according to (Constant, 2000) has two meanings. The *first* is that technological design and practice is a logical or deductive enterprise. In that context four variations are proposed:

Science finds, industry applies (Wrong); Technology has its own logic (wrong, or not proven); Search for solutions to technological problems is logically complete (wrong); Technological problems are logical amenable to algorithmic capture (wrong) (Constant, 2000). The *second* meaning interprets technological practice as intentional purposeful and goal directed; therefore technological change is neither fully rational nor irrational in the sense of an ignorant uniformed process. Instead, the process is a-rational insights that are the product of blind variation and selective retention (Constant, 2000). Consequently the evolution of technology could be following neither the Darwinian nor the Lamarckian tracks; it is rather a set of selection of processes, not one model in all its details (Constant, 2000).

DNA is the main method of replication for biological organisms. How can this DNA model be paralleled in our context? Fleck (2000) answers this question by asserting that technologies require knowledge that is stored tacitly in skilled workers. Pacey (1983) called for a broad notion of 'Technology Practice'; therefore, technology could be resumed in a practice, such as the practice of medicine (Fleck, 2000). According to Pacey, it is all tied to cultural values. Artifacts are not just pure material; they are an embodiment of human and organizational practices and procedures. Therefore the notion of learning-by-doing and learning-by-using to generate knowledge will be central to our forthcoming argument of the evolution of those practices. As a consequence, products and technologies themselves cannot fit the Darwinian evolutionary theory, because according to the authors it is like focusing on the "bones and ignoring the soft tissues". Knowledge is then the key. (Fleck, 2000)

Knowledge

Knowledge inside any environment, consists of ideas, written reports categorized as either tacit or explicit knowledge types, like that embedded in firms' employees (Mokyr, 2000) This type of knowledge is the main element that governs the evolutionary structure (Mokyr, 2000). In Dawkin's (1976) definition, a unit of that knowledge is labeled 'meme'. This structure of the environmental knowledge constrains firms' traits or characteristics but does not fully define it (Mokyr, 2000), technology is only a subset of useful knowledge. The term knowledge therefore does not only represent scientific knowledge but also includes a larger set of business practices that make a certain technology selection (Mokyr, 2000). This view is consistent with that of David's introducing learning-by-using and learning-by-doing (Arrow, 1962) hence, supporting this knowledge based view of the firm. Furthermore, he asserts that organizational capabilities contain complex forms of knowledge that no one single individual can comprehend or hold (David, 2000).

Mokyr (2000), Constant (2000) and Stankiewicz (2000) all concentrate on knowledge base of the firms and their core competencies. Therefore a meme is the unit behaving like a gene from an evolutionary perspective. The problem here is that memes do not distinguish between ideas and practices; which is really important (Fleck, 2000). The survey questionnaire used in our analysis however solidifies the link between the technology, knowledge and practice. This view therefore, will be a mirror to the real world interaction (Vincenti, 2000), which includes the various organizational aspects (Nelson, 2000; Fairtlough, 2000). Another issue when using this knowledge-based view is that it lacks the human agency. While the survey questionnaire overcomes such an issue it remains to acknowledge that knowledge is necessary but not fully sufficient however (Fleck, 2000)

Technology as Practice and Knowledge

From our previous analysis it becomes clear that the socio-economic, cultural and technical knowledge are all significant in technology practice. As a result we can abstract technological products as historical fragments of human and social enterprise (Burns, 2000). It is important therefore not to isolate developing technologies from their social environment, and the social groups within which they try to fit (Burns, 2000). Institutions are a perfect carrier of such a knowledge-based setup, where for instance “technological evolution can be altered by institutional changes that bring knowledge and beliefs of different social groups into the variation selection replication cycle” (Burns, 2000). According to (Burns, 2000), memes are major players motivating technological change. They compose the various components of human knowledge and the collective activities of various human groups including crafts guilds, industrial corporations, R&D and the various institutions. Therefore, the technological evolution cycle highly depends on memes or techno memes in the technological context (Burns, 2000). On the demand side, the evolutionary perspective is about users’ accumulated knowledge and about linkages between services of tools and wants. There is a large amount of historical evidence that societies often tried to avoid hardship labor by advancing technical progress (Mokyr, 1990; Cordes, 2005).

1.4 Major Research Hypothesis

Based on the above this research work will address the following major hypothesis:

H1: The HT sector has matured and we are currently witnessing a renewal and transformation phase, following the trajectory of the electronics sector (Robertson et al., 2009).

H2: The innovation strategic context for LMT in leading economies will be as advanced as its HT sector (Robertson and Patel, 2007). This level will be similar as well in Catching up economies, but with a lesser magnitude then in leading economies.

H3: An evolutionary approach using phylogenetic trees is appropriate for the classification of SIs and for the reconstruction of history from an evolutionary perspective.

The following chapter will address the approach\methdology used for each hypothsis.

Chapitre 2 RESEARCH APPROACH AND MAJOR HYPOTHESIS

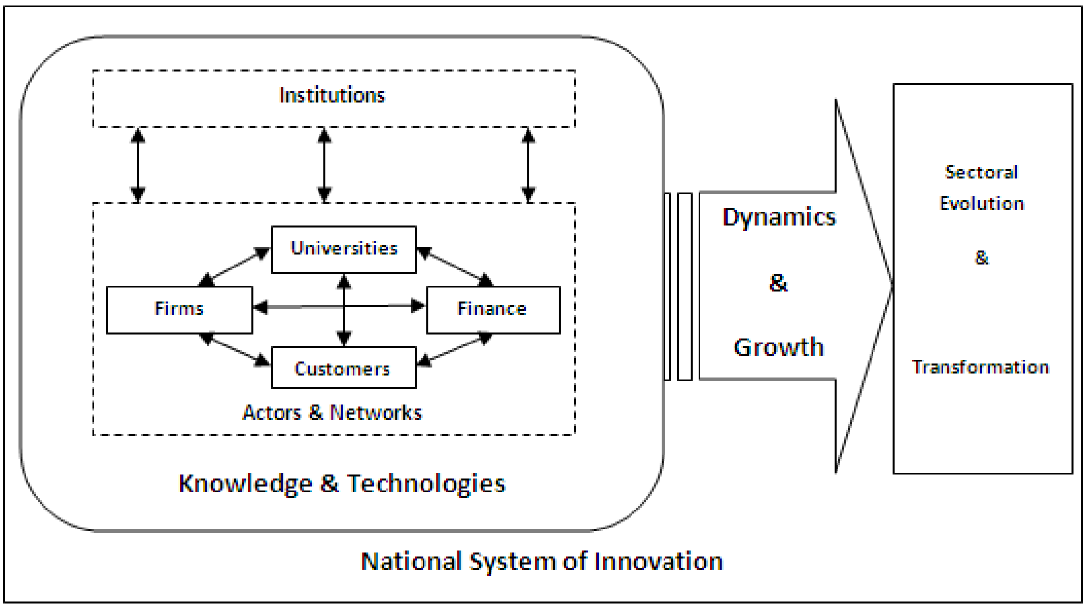
2.1 Research Objective

The objective of this research work is therefore to capture the main differences between the HT and LMT, and test whether the sectors are undergoing any transformation or renewal processes. Second is to introduce the national systems of innovation and test if the national systems of innovation play a key role into those sectoral dynamics. The third and final is to add the time dimension by capturing the evolution of those systems of innovations and test if they match the findings of the first and second hypothesis.

2.2 Theoretical Framework

The theoretical framework governing this research work follows that of Malerba (2004). In that framework the various agents operating in the boundaries of the Sectoral and National systems of innovations are presented.

Figure 2. 1 Theoretical Framework based on Malerba (2004)



In figure 2.1, the sectoral system is presented by the various sectoral agents, including firms, customers and institutions. Institutions can be governmental, or academic and financial institutions. Those entities are presented from a knowledge based view. This knowledge based view allows, knowledge circulations between the various agents. This disembodiment of knowledge permits us to understand the systems of innovation from an evolutionary perspecive.

Table 2.1 identifies the factors that explain the theoretical framework. The same factors are used to address the three major research hypothesis. Each factor will hold a different label in different chapters to fit the scene of the paper\chapter. For the sake of simplicity, I hereby will use the naming convention used in chapter 5 labled numbers from 1 to 32 for each factor associated to explain its origins in the litterature following Malerba (2004).

"Evolutionary theory provides a broad theoretical framework for the concept of sectoral systems of innovation" (Malerba, 2004, p. 14) because it places the sectoral dynamics that include learning and knowledge (Factors : 3,4,6,9) at the center of the analysis. Where for instance, the interactions between those various entities leads to sectoral dynamics and growth that later leads to sectoral evolution and transformation as presented in the arrows in figure 2.1. Of course, those sectoral boundaries are also nationally bounded. Therefore, this whole theoretical framework is in close interaction with the national systems of innovations those sectors are located.

Consequently, various cognitive aspects affect the learning process (Nelson, 1995; Dosi, 1997; Metcalfe, 1998). Agents or population of agents are subject to bounded rationality. Hence their rationally bounded decisions are contained and bounded by various factors that include technology, knowledge base and the institutional context in which agents operate (Malerba, 2004). Sutton's (1991, 1998) taxonomy for instance takes into consideration the inability of the firm to control or foresee factors that are beyond a firm's ability to invest in a certain technology or not (Von Tunzelmann, and Acha, 2005). This argument supports the 'bounded rationality' paradigm. Hence, it supports the randomness of variation that characterizes the Darwinian evolution. Knowledge therefore is able to redefine sectors boundaries (Factors: 28,29), and re-shape the innovation process. Additionally, knowledge does not diffuse automatically and freely between firms (6), but has to be absorbed through time (Malerba, 2005). As a result firms facing the same environment, share the same set of learning patterns, organizational forms and behavior (Malerba, 2004). Consequently, following an evolutionary argument, sectors should differ clearly (Pavitt, 1984) across those various factors we will later introduce. Evolution, as discussed, is generally about variation and natural selection. Malerba (2004, 2005) identifies the evolutionary approach on three basic axes: variety creation (technologies, products, and firms), replication (promoting inertia and continuity) and selection (reducing the variety and discouraging ineffective utilization of resources). Variety creation includes products (Factors: 15,16), technologies (Factors: 7,8,14,26), institutions (Factors: 10,11,12,20), firms, strategies (Factors: 17,19,25,30,31,32) and behavior. The severity of selection is sector dependent (Malerba, 2004).

Consequently, new knowledge and technologies are created (Factors: 2,4,5,6,7,8,9) (Nelson and Rosenberg, 1993) thus contributing to sectoral system differentiation. Additionally, new firm entry, with new products, technologies (Factor: 25), know-how, knowledge, as well as universities (Factors: 3,4) and sectoral institutions add to this sectoral differentiation (Audretsch, 1996; Geroski, 1995; Malerba and Orsenigo, 1999). Consequently, the evolutionary approach that reinforces the notions of selection and variety generation considerably better explains industrial dynamics and sectoral transformation of sectoral systems (Factors: 24,27,28,29). The evolutionary approach also includes beliefs, objectives and expectations (Malerba, 2005).

This co-evolution and transformation of sectoral systems could occur on the technological regime, learning regimes or patterns of innovation (Malerba, 2004). Innovation activities might shift from a Schumpeter mark I to mark II or vice versa. The knowledge base might change incrementally (Factor: 18) or radically (Factor: 25). In the case of incremental increase (Factor: 18) in the knowledge base, a dominant design emerges and large enterprises dominate (Utterback, 1994). In the case of breakthrough knowledge, however, new technology producing firm entries are encouraged (Jovanovic and MacDonald, 1994; Tushman and Anderson, 1986; Henderson and Clark, 1990; or on the user\demand side,Christensen and Rosenbloom, 1995). Therefore according to Malerba (2004), this co-evolutionary process is sector specific and affects various elements including technology, demand (Factors: 1,2), the knowledge base (Factors: 3 to 9), and learning processes, as well as firms, non-firm organizations and institutions.

Table 2. 1 Factors explaining the theoretical framework

Factors \ Chapters, Papers & Variables	Chapter 3 (1st paper Variables)	Chapter 4 (2nd paper Variables)	Chapter 5 (3rd paper Variables)
1-Nature of customers and of their needs			
Customer and product operation	Cust_Expert_H5	ANExp	1
Customers needs complexity	Cust_Need_H5	ANComp	2
2- Technical knowledge production mechanism			
Intensity of knowledge production through univ.	Univ_KnowInt_H7	ANUniv1	3
Sectors contribution to scientific knowledge	Univ__KnowCont_H7	ANUniv2	4
Sectors systems integration	Sup__Know_H6	KTSys	5
Knowledge production through interaction	Know__Firms_H4	KTOut	6
Technologies build on latest technologies	Know_Tech_H4	KTStab1	7
Firms reliability on a stable tech. base	Know__Depend_H4	KTStab2	8
Knowledge accumulation from inside the firm	Know_Grad_H4	KTIn	9
3- Factors influencing innovation in firm's sector			
Reg. approval critical for commercialization	Gov__Regu_H9	IReg	10
Time and resources deter me too innovation	Comp_Regu_H8	IRegIm	11
IP protection to capture value	Comp_Val_H8	IIP	12
General Purpose Technologies (GPT)	Tech_GPT_H3	KGpt	13
Utilization of diff. tech. in firms products	Sup_Tech_H6	ANSupp	14
Products interconnectability	Sup__Ext_H6	ANMod	15
Products dependability	Sup__Trans_H6	ANStd	16
Cost reduction	Strat__CostScale_H1	ANCostScl	17
Process innovation	Strat_ProdProc_H1	ANInnov	18
Cost based competition	Strat_Cost_H1	ANCost	19
4- Resource inflows and growth in the sector			
Government allocating resources	Gov_Res_H9	IGov	20
Ease of startup funds	Strat_Fund_H1	ANFin	21
Sales growth	Strat_Sales_H1	DGGrowth	22
High sales growth through new niches	Strat_Niche_H1	DGNiche	23
5- Competitive dynamics in the sector			
Comparative high pace of change	Comp_Change_H8	DGPace	24
Entry with breakthrough innovations	Comp_Prod_H8	DGEntry	25
Rapid advancement of technological frontier	Tech_Speed_H3	ETTech	26
Unpredictable transformation by externalities	Strat_Trans_H1	ETTrans	27
Sectoral boundaries redefinition	Tech_Sect_H3	ETRedef	28
Anticipated sectoral development	AbCp_H2	ETDev	29
Incumbent competition	Comp_Rival_H8	DGIchal	30
Competition eroding advantage	Comp_Advant_H8	DGRchal	31
Cost Competition	Comp_CostSub_H8	DGCost	32

Case studies of high technology (HT) sectors reviewed by Malerba (2004) demonstrate the following. Interaction between knowledge (Factors: 3 to 9), actors (Factors: 1 to 9) and institutions (Fators: 10,11,12,20) shaped the evolution of the system of innovation in the pharmaceutical sector. Weaker protection (Factors: 10,11,12) induced imitative strategies (Factor: 11), and stronger ones led the Italian generics industry to disappear in this sector (McKelvey *et al.*, 2004). Oligopolistic structures started in the telecom sector due to the separation of telephony and broadband. However, the convergence motivated a fluid market structure, with new actors and users (Factors: 1,2). Open standards were created and new actors rose such as ISP and ICPs[1] in the telecommunication sector (Edquist, 2004). Growth of software products emerged due to the role of open standards (Factor: 15) and open source approach, various licensing agreements emerged in the software sector. Generic products that hold customization utilities (Factors: 14,15,16) have emerged. Internal firm specializations (Factor: 9) emerged to this need for providing highly customizable products (Factors: 15,16) in this sector (Steinmueller, 2004).

Case studies of low and medium technology (LMT) sectors also reviewed by Malerba (2004) demonstrate the following. Technology (Factors: 7,8,14), demand, markets and institutions shaped the co-evolutionary process in the chemical sector (Cesaroni *et al.*, 2004). Environmental issues further shaped the co-evolutionary process in this sector. Developed countries have observed the rise of environmentally safe products. Governments (Factors: 10,20,21) imposed regulations (Factors: 10,11,12) to minimize pollution. Firms in the sectors used process innovation (Factor: 18) to make their products greener. Demand from advanced customers (automotive, aerospace and defense) (Factors: 1,2) shaped the machine tools industry, thus incremental innovation became dominant. Patenting (Factors: 10,11,12) has been growing strongly in recent years. Furthermore, computer scientists became more needed in this sector (Wengel and Shapira, 2004).

Mowery and Nelson (1999) study the long-term evolution of various sectors over time and across countries. They demonstrate that co-evolutionary processes differ greatly across sectors. Some are motivated by sales growth (Factors: 22,23) and radical product development (Factor: 25),

---

[1] Internet Service Providers (ISP) & Internet Content Providers (ICP)

while other sectors are mainly dependent on technologies (Factors: 7,8,14), demand, institutions and firm organization as well as strategy. This process of co-evolution between the different sectoral agents is sector specific and path dependent (Malerba, 2004).

2.3 Data Description

Data used is the data collected throughtout the MINE project (2005-2007). The MINE project survey's main goal was to identify the various ways value is created, and captured. Hence, the scope of analysis included orgniaztional policies, strategies, innovation management practices, and R&D structures. The aim in this strategy only covers the sectroal dynamics. Therefore out of the multiple sections included in the survey, only the first section addressing the context of firm's innovation in firm's own sector is examined. In that 5 axis are examined throughout this research work. The first is Demand, second, is knowledge production mechanisms, third is factors influencing innovation in the firm's own sectors, fourth, the resource inflows and growth in the sector, and finally fifth, the dynamics occurring in the sector. As previously explained the factors included in that part is based on Malerba (2004)'s conceptualization of the sectoral systems of innovations. Data is crossectional and does not address the historical factor. Since the data perfectly fits the first two research hypothesis, the time element is not included to provide the historical dimension. Section 2.4.1 will address the first two hypotheses. Section 2.4.2 will address the missing time dimension to the data, by examining the phylogenetic trees approach.

It is important to mention that the sizes of firms are diversified. The following tables (2.2 and 2.3) will show the number of firms with the resepect to firms' sizes in the studied samples used in the study.

Table 2. 2 Firms' sizes in Leading and Catching Ups

Criteria		Leading	Catching Up	Total
Small (<100)	Count	120	45	165
	% within Employment Category	72.7%	27.3%	100.0%
	% within Industrialization Category	39.2%	18.8%	30.3%
	% of Total	22.0%	8.3%	30.3%
Medium (>100 & <500)	Count	43	62	105
	% within Employment Category	41.0%	59.0%	100.0%
	% within Industrialization Category	14.1%	25.9%	19.3%
	% of Total	7.9%	11.4%	19.3%
Large (>500)	Count	143	132	275
	% within Employment Category	52.0%	48.0%	100.0%
	% within Industrialization Category	46.7%	55.2%	50.5%
	% of Total	26.2%	24.2%	50.5%
Total	Count	306	239	545
	% within Employment Category	56.1%	43.9%	100.0%
	% within Industrialization Category	100.0%	100.0%	100.0%
	% of Total	56.1%	43.9%	100.0%

Table 2. 3 Firms' sizes in HT and LMT

Criteria		HT	LMT	Total
Small (<100)	Count	92	137	229
	% within Employment Category	40.2%	59.8%	100.0%
	% within Sector Category	33.7%	29.6%	31.1%
	% of Total	12.5%	18.6%	31.1%
Medium (>100 & <500)	Count	54	85	139
	% within Employment Category	38.8%	61.2%	100.0%
	% within Sector Category	19.8%	18.4%	18.9%
	% of Total	7.3%	11.5%	18.9%
Large (>500)	Count	127	241	368
	% within Employment Category	34.5%	65.5%	100.0%
	% within Sector Category	46.5%	52.1%	50.0%
	% of Total	17.3%	32.7%	50.0%
Total	Count	273	463	736
	% within Employment Category	37.1%	62.9%	100.0%
	% within Sector Category	100.0%	100.0%	100.0%
	% of Total	37.1%	62.9%	100.0%

2.4 Research Methodology

2.4.1 Comparative Approach (H1 & H2)

In order to address the first two major research hypotheses, t-test of equality of means are used in order to carry out the comparisons between the various systems of innovation and with respect to the five identified axes (Shown in Table 2.2). With respect to major research hypotheses H1 and H2, the methodology used, with the data description is explained in details in the methodology sections of each of the chapters 2 and 3 respectively. As previously explained, the research work will be using the first section of the Managing Innovation in the New Economy (MINE) survey. This first section addresses the innovation context in the firm's own sector. Since each chapter (2, 3 and 4) will be handling the data a bit differently due to the difference in the theoretical frameworks proposed, Table 2.2 introduces the survey elements, with its variable names. This way a unified view for the reader will enable further understanding of the results and findings.

The answers on the survey are presented in a Likert Scale from 1-7, where 1 denoting the respondent 'totally disagree', and 7 denoting 'totally agree'. The first hypothesis will be tested by including 736 firms of the MINE database. The HT represented by 273 firms, and the LMT of 463 firms. The second hypothesis needed to identify the countries where firms are located. Some firms had the countries missing, therefore were removed from the database. Consequently, the total number of firms reduced from 736 firms to 545 firms to test the second hypothesis. In that, HT leading economies were represented by 111 firms. The HT Catching up economies, by 88 firms, LMT leading economies by 195 firms, and finally LMT Catching up economies by 151 firms.

Table 2.4 below presents the sectoral\economies segmentation matrix.

Table 2. 4 Sectoral\Economies segmentation

HT Leading 111 firms	HT Catching up 88 firms
LMT Leading 195 firms	LMT Catching up 151 firms

Sectors representing the HT include the ICT including telecommunication and information technology firms, pharmaceutical and biotechnology firms, and the aerospace. The LMT is represented by the manufacturing, automobile, pulp and paper as well as the services sector. Leading economies are presented by Canada, France, UK and USA. Catching up economies are presented by China, Taiwan, South Korea and Peru. Peru was included to represent Latin America, since it exhibited unprecedented growth in the year 2007 that amounts to 9% due to aggressive govrnmental trade liberization strategy. (Please see www.cia.gov).

Axis one, targets the nature of customers and their needs. This axis is presented by two questions. The first addresses the extent by which customers provide significant expertise about the firm's product operation. Furthermore, it addresses the complexity of customer needs in the second question.

The second axis addresses the technical knowledge production mechanism. It addresses, the intensity of knowledge production through:- the academic field, the magnitude of data, papers and ideas to academic research, the integration of systems and equipment, the interaction between firms, building on other firm's technologies, reliability on a stable technological base, and finally through the gradual accumulation of knowledge from within the firm.

The third axis addresses the factors that influence innovation, in the firm's own sector. It addresses how critical the regulatory approval is for the commercialization of new products, the time and resources needed to limit imitation strategies, the role of intellectual property to enable firms capture value from innovations, the generality of application of the technologies produced, the variety of technology used in the firm's own products, the inter-connect ability of the firm's products with others, the reliability on many other technical systems, the cost constraints and reduction mechanisms, and finally the role of process innovation compared to product innovation.

The fourth axis addresses the resource inflows and growth in the firm's own sector. It addresses the governmental allocation of resources to support research and innovation, innovative startup's ability to access funding. Growth is addressed by addressing the comparative sectoral growth compared to other sectors, and the sales growth with the firm's own sector.

The fifth and final axis addresses the strategic and competitive dynamics in the sector. It addresses the pace of change compared to other sectors, market entry for competition due to innovative products production, the rapidity by which the technological frontier is advancing, the external factors forcing unpredictable transformations, the sectoral boundaries redefinition, un anticipated significant sectoral development, incumbent challenge, rivalry strategies, and finally the attacks by low cost substitutes.

The data used in the survey holds a main disadvantage is that it is subject to the agency problem. For instance the respondents might be encourage following a certain answer or not, or due to competition or position in the company agents might not be very encouraged to give the most accurate answer. Furthermore, the perception of the respondents could be different throughout the questionnaire for the different firms, therefore it might lead to some variation in the answers.

The advantage of this questionnaire is that its first section perfectly address the factors used to analyze any generic system of innovation. Hence the factors used perfectly fit the main research questions. Moreover, the questionnaire addresses perceptions, and opinions, therefore respondents answers could be easily be transformed to culture memes subject to evolution (The third research hypothesis H3)

2.4.2 Phylogenetic Tree Approach (H3)

Before proceeding with the methodology used to build the phylogenetic tree, a general introduction aims to give a general view of the tools used in evolutionary economies to address the various policy, and micro economic issues. In evolutionary economics simulation is greatly useful when studying complex socio-economic behavior. The main advantage of simulations over analytical methods, is that it is not bound by constraints (Nelson, 1982). One main disadvantage of orthodox modeling is that it does not take into consideration, the model's time dependence. Due to this, simulation in the field of Industrial Organization (IO) developed to be a widely used tool for researchers, policy and decision makers. Examples of simulations from the field of IO are numerous, for instance, (Malerba, Nelson, Orsenigo and Winter, 2001) implemented a simulation model to understand the dynamics of competition and industrial policies and its effect on the computer industry. The researchers targeted antitrust and intervention policies that aim at protecting new entrants in a given industry. The model they built takes into account several variables that affect firms' decision, such as its pricing strategy, R&D cost, and advertising expenses. In the same vein, (Malerba and Orsenigo, 2001) have studied the market structure and regulations, and how they affect the pharmaceutical industry using an innovation history friendly model. The study indicated a low level of concentration in the aggregate market, and highlighted the importance of innovative firms to foster the industry's overall innovative capacity. Moreover, the study showed that the role of innovative firms is affected by demand growth, together with the increase in technological opportunities. On the patents side, the study showed that an increase in the patent protection, leads to greater concentration.

In addition to the above growth models, game theory has been widely used to model the strategic behavior of firms with respect to R&D management. Game theory is one of the tools used by Industrial Organization (IO) economists to understand behavior of firms and industries as a whole. Before the emergence of game theory, IO economists used industry analysis or cross section regression studies to analyze firms/industries (Shaprio, 1989). Game theory, according to Shapiro (1989), is the only coherent tool of logically studying strategic behavior of firms. The application of game theory touches various fields of concern such as: investment in physical capital, investment in intangible assets, strategic control of information, horizontal mergers, network competition and product standardization, contracting, and others. In what follows I will target the use of game theory to model the strategic behavior of firms in R&D.

With respect to *investment in R&D,* as R&D is considered an intangible asset, investments can generate intellectual property, or know-how that is crucial for enhancing the competitive position of a firm. Funding of R&D is an important example of investing into the firm's intangible asset (Shapiro, 1989). Park (1987) investigated equilibrium R&D investment, for firms that hold different innovation potentials. In his model he assumed a two-stage game, with two players (firms). With respect to *Collaboration in R&D,* Katz (1986) has analyzed the effects of cooperative research. In his analysis, member firms agree to share the costs and benefits of a research project before undertaking it. Katz (1986) investigated the Nash perfect equilibrium of the game, by using the backward induction method. In the game formulation, the number of players can include up to N number of players (firms). Before competing in the stage of production, each firm choose its level of R&D while using as given the parameters of any cooperative research agreement. If a firm does not commit to the cooperative research agreement it goes on its own and bears all of its R&D costs. If firms use the cooperative agreement, costs are shared among firms (Katz, 1986). Prior to choosing their R&D levels, member firms in the cooperative R&D chose the R&D cost, and the output sharing rules, while taking into consideration the equilibrium of the development and production stages respectively. In the membership stage, n-firm agreement maximizes the industry profits. Firms will form an industry wide agreement if side payments with compared to membership decision are feasible (Katz, 1986). If we examine the output and welfare effects of the four stage game, it is noted that the cooperative research agreement can have couple of effects on welfare. First, the agreement motivates sharing between partners, and lowers the expenditures needed to achieve a certain level of R&D. Second, the agreement affects equilibrium level of effective R&D.

Amir (2003) used game theory to develop a two-stage model of *Product market competition and R&D*. The prime aim of the model is to provide an in depth generalization of previous results targeting the comparative performance of cooperative and non-cooperative R&D within research joint ventures (RJV). The model, takes into consideration the structure of the profit maximizing R&D cartels. This model handles the case where firms competing in a product market, jointly start to cooperate on R&D expenditures, as well as internal spillovers.

With respect to *Diffusion of a new technology,* Reinganum (1981) has modeled diffusion of new technology. She considered an industry that consists of two firms that use the best technology. An assumption is that both firms are operating at Nash equilibrium output level (Reinganum, 1981). The model assumes that a given time, an innovation is announced. This innovation will enable reduce firms costs and consequently increase its profits. Consequently, both firms should take the decision whether to adopt the technology or not. The strategy adopted is based on two basic factors: the amount of discounted cost of adopting the new technology, and the strategy of the other competitive firm.

In what was presented, models start with a predefined set of rules\parameters that the modeler chooses. Those models are quit efficient to understand the impact of policy formulations from an evolutionary perspective. However, those models cannot serve us to understand historical occurrence, or for any classification purposes. Before presenting the proposed methodology, it is important to note that if we non-carefully examine the innovation phenomenon from a bird eye view, one might seem encouraged to think it is extremely random, due to the complexity of the innovation process. Such a stand is the same that one can defend with respect to any chaotically observed phenomenon. Chaos theory states that deterministic laws can finally breed apparently unpredictable structures (Stewart, 2003).

While the deep emergence in chaos theory is not needed in our context, mentioning it only clarifies that in the mid of apparently chaotic data, some hidden apparent structures are still there to exist. The question is just how. Data collected is cross sectional meaning the absence of any historical data. Evolutionary biologists face the same problem. They collect huge amounts of DNA structures and try from that cross sectional data build evolutionary structures. The main tool is by building phylogenetic trees. Building phylogenetic trees can therefore serve in classification of species, as well as to study the evolution of species characteristics across the evolutionary tree.

One of the most widely used techniques used to construct phylogenetic trees is parsimony. Parsimony methodology advocates the use of the minimum number of evolutionary steps in order to come up with the best tree that presents a set of data. It is important to mention that for the more number of species\firms we have, the higher the number of trees to be tested in order to come with the most parsimonious tree. For instance, for 2 species we need 1 rooted tree. For 3 species, 3 possible taxonomies should be tried. Ten species can be represented by more than 34 million trees (Felsenstein, 2004). The PHYLIP software can solve this algorithmic problem to solve problems with high number of species (Like in our case, 500+ and 700+ firms illustrated before).

Let us consider 3 firms, with 4 characteristics. Characteristics are coded in binary format. ‘0’ highlights a characteristic that does not exist, while a ‘1’ an existing character. For 3 firms, 3 taxonomies are available as in the Table 2.5 below:

Table 2. 5 Firms and characteristics table

Firms\Characteristics	Char 1	Char 2	Char 3	Char 4
Firm A	0	0	0	0
Firm B	1	1	0	0
Firm C	1	1	1	1

The number of trees space is calculated by the formula: $\frac{(2n-3)!}{2^{n-2}(n-2)!}$ where n is the number of firms (Felsenstein, 2004). The first 10 firms, shown as an example are presented in Table 2.6 below.

Table 2. 6 Species and number of trees (Source: Felsenstein, 2004)

Species\Firms	Number of Trees
1	1
2	1
3	3
4	15
5	105
6	945
7	10,395
8	135,135
9	2,027,025
10	34,459,425

Figure 2.3 shows the 3 possible taxonomies for three firms with a rooted tree.

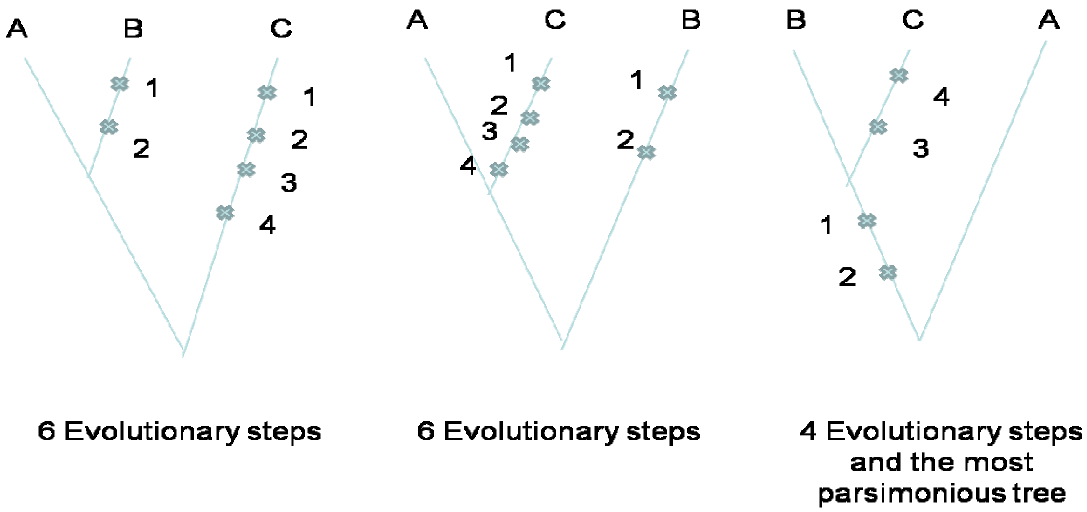


Figure 2. 2 Three tree taxonomies: represents data in Table 2.5, where the tree on the extreme right as the most parsimonious tree with 4 evolutionary steps.

For the first taxonomy (Extreme left in figure 2.3). We assume all characteristics start from 0 status. In other words, each characteristics initial setting is 0 (or does not exist). Starting with characteristic 1 at the root, firm A will remain 0, while B and C will change status from 0 to 1. Therefore, we mark 1 on the C branch, and 1 on the B branch (2 steps). Moving to characteristic 2, same as characteristic one, A will stay 0, while B and C will change status from 0 to 1 (2 steps). For characteristics 3 and 4, only firm C will change the status from 0 to 1 (2 steps). Therefore the total number of evolutionary steps is 6 steps, to represent the 3 firms (A, B and C), with the 4 characteristics as shown in Table 2.5.

If we examine the middle taxonomy, it is intuitive to have the same number of evolutionary steps as the first taxonomy since, the branch alignment, and the data representation is an exact mirror like. Therefore, Characteristic 1 will take 2 steps, characteristic 2, 2 steps, while three and four, 1 step each resulting in two additional steps. Therefore the total number of steps is 6 steps, as well.

If we consider the last taxonomy (extreme left), the number of steps will be different due to the change in the tree taxonomy. In the third case, since firms B and C share the same change for characteristics 1 and 2, it is enough to place them second to the root. This saved two additional steps needed if they were separated as the previous two taxonomies. Changes occurring to Characteristics 3 and 4 however, are a sole characteristic for firm C; therefore it always adds two steps. Therefore the total number of evolutionary steps in that case is 4 steps. This taxonomy (extreme right) is the most parsimonious tree.

In other words, if we take the tree at the left, we can see that it takes 6 evolutionary steps to represent data in Table 2.5. The best method to spot the evolution is to start by characteristics. The first characteristic (char 1) is represented by 0,1 and 1 for firms A, B and C respectively. In this example, we assume characteristics change status from 0 to 1. So to represent Char 1, Firm A, has a ‘0’ implying no change in status. However, for the same characteristic, firms B and C both hold 1s. That needs two steps. The same goes for characteristic 2, A keeps the 0 status, while B and C change their status, that needs two additional steps. For characteristic 3 and 4, only firm C needs to the status from 0 to 1, and that needs additional 2 steps. The total steps then for the overall representation of characteristics in Table 2.3 for the first taxonomy is 6 steps. Now we move to the second taxonomy (the middle one). In that case, if we follow the same process, it will result in 6 evolutionary steps as well. If we follow the same process for the third (on the extreme right) taxonomy, this will result into 4 evolutionary steps. Therefore the last tree is selected as the most parsimonious tree, in the tree space representing data in Table 2.5.

This solution is informative. If we look to figure 2.3, we can see that firms B and C, are the most similar, and that is what is coined the “common shared derived characteristics” approach. As we have seen, firm A did not witness any change in any characteristics, where it stayed in a 0 status for all characteristics. This makes firm A quit distinguishable from firms B and C. Firms B and C however, they went through more common changes. Therefore, when constructing the tree, the taxonomy that separated A the most, and grouped B and C the closest, was the one with the minimum number of evolutionary steps. The first two taxonomies (the left and the middle), put firm A together with firms B, and C on the same sub branch respectively. For this reason, it took more evolutionary steps, showing that this is not the optimum taxonomy that represents the data.

Furthermore, assuming common ancestors, characteristics 1 and 2, are common between firms B and C. Therefore the characteristics had to go through one change only, since the taxonomy allowed having these changes at the root. Therefore, these characteristics did not have to go through any changes at the final branch tips. That is the reason why this technique is suitable to classify the firms, as well as to understand the evolution of characteristics across the most parsimonious tree.

2.5 Research Approach

This research will be conducted in three main steps. The first major hypothesis (H1) will aim to highlight the differences between, and the dynamics of, HT and LMT. This will enable us test the first major hypothesis (H1):

H1: The HT sector has matured and we are currently witnessing a renewal and transformation phase, following the trajectory of the electronics sector (Robertson et al., 2009).

The first major hypothesis will be the focus of Chapter 3.

The second major hypothesis (H2) aims to highlight the differences between the two sectors, LMT and HT, with respect to leading and catching-up economies. According to Robertson and Patel (2007) and Mendonca (2009), economies excelling in HT are most likely to excel in LMT. This will enable us test the second major hypothesis (H2):

H2: The innovation strategic context for LMT in leading economies will be as advanced as its HT sector. This level will be similar as well in Catching up economies, but with a lesser magnitude then in leading economies.

The second major hypothesis will be the focus of Chapter 4.

The third major hypothesis will be rather exploratory and will serve to analyze the National and Sectoral Systems of Innovations (SI) from an evolutionary perspective. The evolutionary approach will serve to assess the classification of SIs and to reconstruct history from an evolutionary perspective. This formulates our third and last major hypothesis (H3):

H3: An evolutionary approach using phylogenetic trees is appropriate for the classification of SIs and for the reconstruction of history from an evolutionary perspective.

The third major hypothesis will be the focus of Chapter 5.

The comparative approach will be with respect to five sectoral systems of innovation axes: demand, knowledge production mechanisms, various factors affecting innovation in the studied sectors, resource inflows and growth in the sector and finally dynamics in the sector resulting from various competitive strategies.

The five axes will constitute the selected variables from the ‘context of innovation in your sector’ section in the MINE survey questionnaire (Please look table 2.2). The first axis will target demand, including the nature of customer and their needs. This axis addresses the customer’s expertise, and complexity of needs. The second axis will address the knowledge production mechanisms. In this axis, knowledge production mechanisms include knowledge generation from the academic field, through systems integration, inter-firms interactions, or gradual accumulation inside the firm. The third axis will include the various factors influencing innovation in the firm’s own sector. This axis include regulatory approvals, intellectual property protection (IPP), products inter-connect ability, process\product innovation and cost constraints. The fourth axis, addresses the resource inflows and growth in the firm’s own sector. In that axis, government support to Research and Development (R&D), ease of startup funds and sales are addressed. The final and fifth axis will include the strategic and competitive dynamics in the sector. This axis addresses the pace of change, entry, incumbent vs. rival competition, cost competition, as well as sectoral transformation and redefinitions. Table 2.1 hereafter present the various axes, and variables used with the corresponding variable names in this research work.

The first research question targets the main differences between HT and LMT, with respect to the above-mentioned axes. Chapter 3 addresses the first research question, and the major research **hypothesis (H1)**. **The second research question,** adds a second dimension to the sectoral systems of innovation. In that, two supranational groups\economies, leading and catching up economies, are compared with respect to the two sectors and the same axes. By this, I aim to understand whether national systems of innovation contribute to the differences found between the two sectors or not. This will mark the introduction of the second major research **hypothesis (H2)**. Chapter 4 addresses the second research question. **The third research** question will investigate the differences between the two systems of innovations (National and Sectoral) from an evolutionary perspective using phylogenetic tree analysis. Such a technique enables us to classify and understand the characteristics of firms belonging to both systems of innovations. Furthermore, the technique enables us trace characteristics, and their evolution in a stepwise fashion. This will address the third and last major research **hypothesis (H3)**. Chapter 5 addresses the third and final research question.

2.6 Important Remarks, Limitations and Some Critiques

Before proceeding to the research work it is important to address some important remarks, limitations and critiques. Some of the critiques of this research work address the broad definition of HT, versus LMT. Of course the HT can hold several charactersitics. For instance it is currently the most targeted for growth, often concerend with product innovation, holds R&D expenditure more than 5% of business revenue and others. All these definitions are viable. For the time being, sectors characterized with all the above are the Biotechnology, Pharamaceuticals, Telecom and ICT and Aerospace. Such a broad definition is based on the OECD classification used for instance by the Australian Government, Departement of Innovation, Industry, Science and Research for year 2008. Same applies to the Low and Medium techs when the Australian government launched a recent research study addressing the LMT sector. Of course this highly aggregate form holds some disadvantages, since it does not address sectors specifities. However, such an approach enabled addressing the sectoral evolution in a much precise way. That is, when dealing with evolution, in an ecosystem, the larger the population of firms is, the more adequate the result of the evolutionary tree is. This was one of the main reasons going through such a highly aggregate sample. Furthermore, while such an aggregation might not offer the accuracy needed when performing case studies for instance, the approach is usefull addressing policy related issues, like the ones presented in Research Policy (2009).

It is also important to mention that while labeling HT as a provider of tools and materials; here I am addressing the technologies produced by the HT. In that context, I refer to the important seperation between technology and products (Freddi, 2009). According to Freddi (2009), this anaytical sperararation is important, since « products do not overlap with technologies, but can be instead seen as expressions and embodiments of technologies » (Freddi, 2009, pp549). Therefore, technologies should be thought of as bodies of knowledge. Consequently, the emergence of new products « can distroy existing ones, the same does not apply to the same extent to technologies » (Freddi, 2009, pp549). As a result, while of course HT products are dependent on LMT ones, and vise verca, I argue that technologies, as bodies of knowledge, are generally transferred from HT to LMT.

It is also important to highlight that since this research work is addressing a wider sectoral spectrum, some counter examples exist due to this highly aggregate approach. For example, when stating that the HT firms are generally focused on developing GPTs, it is argued that the pharmaceutical industry does not provide any single medication that rate as a GPT. But here, again we are addressing products vs. technologies. For sure GPTs, cannot be argued to offer general purpose products, rather, they offer the technologies that have the ability to diffuse to other sectors. Examples of which is the biotechnology in food processing and computerised cutting in clothing (Freddi, 2009, pp551).

When assessing the customers and complex needs, it is important to mention that some products provided by the ICT like Google, iTunes, Facebook and others could be generally perceived to address simple needs. However, the complexity of demand lies in other hidden factors, like performance, search time, and accuracy in the case of Google, and that differentiated it from other search engines. The general simple need of using social networks has hidden embedded needs like privacy, security, and database handling technologies that become extremely complex if one considers the numbers of users associated.

The thesis follows a comparative approach. When comparing HT to LMT, I do not address one characterstic of one sector on the absolute level. Therefore, the analysis should be more considered from a comparative, relative stand, not an absolute one. For instance, a hypothesis supporing the fact that LMT is more dependent on collaboration than HT, have to be considered only in relative terms. For instance, it is not arguable that HT highly depends on this kind of collaboration. However, when compared to LMT, I hypothesized that LMT would be more dependent on collaboration, as a vital activity, due to the nature of the industry in general, and its inability to aquire knowledge with other expensive means.

Since the analysis provided hereafter is primarily based on Malerba (2004) theoretical framework, it does not address the role of MNCs despite its importance (Malerba, 2004, pp 34). The importance of the MNCs lies in the cross border generation of innovation and knowledge flows, together with offshore investement in R&D.

Another final critique is regarding the terminology of leading and catching up conomies. It is important to mention that the process of catching up is a highly dynamic process. The terminology of catching up in this research work addresses the process from an innovation perspective rather from a pure economic stand. Furthermore, the terminology is highly relative to the leader and follower. For instance, if we take South Korea as an Example, it is a leader with respect to some emerging and other catching up economies such as Brazil, while in a catching up position, when compared to leading economies such as the United States. This is from an innovation perspective.

Chapitre 3

THE RENEWAL AND TRANSFORMATION OF HIGH, MEDIUM AND LOW TECH: A COMPARATIVE APPROACH

Ziad Rotaba and Catherine Beaudry

International Journal of Technology Marketing

Volume 4, Number 4, 2009

3.1 Abstract

In the past decade, innovation studies have mainly focused on the high tech (HT) sector due to its soaring return on investment, and the critical role it plays building new economies. As a result, the innovation literature focus has deviated from the traditional, low and medium tech (LMT) to HT sectors. This study, among a series of recently published work, stresses the importance of LMT sectors from an innovation perspective. Results suggest that a renewal and transformation is occurring to both sectors. LMT is shifting towards differentiation, while HT is increasing its cost awareness dimension. Furthermore, HT firms are using both the linear model of innovation as well as the open innovation model. Firms in LMT that are generally conceived to be supplier dependent are enhancing their internal knowledge production mechanism to support their differentiation strategy and are still the user of the general purpose technologies that HT produces.

Keywords *- Pavitt taxonomy, Product innovation, Process innovation, Knowledge production, Open innovation, Linear model of innovation*

3.2 Introduction

After the Second World War, the US government lent special attention to various strategic industries. The most important of which were: defence, safety and health (Bruland & Mowery, 2005). This focus materialized by increasing governmental spending to foster Research and Development (R&D) in the targeted sectors. As a government intervention policy, R&D industrial funding became more rooted in the development of the various target industries. This laid the definition of the 'Linear Model' of innovation; a model that relies in its core premises on boosting internal R&D to invent new technologies. Consequent to this Schumpeterian (Mark II) movement, the HT sector evolved rapidly to include large incumbent firms. Those firms were R&D centric, and basically created demand through their radical innovations. Pushing technologies and educating the customer base, were the main ingredient of those large firm's core strategic directive. This Mark II era, typically from 1945 to 1980, was characterized by weak formal protection. Not a surprising assertion indeed, since most of the firms at that time depended on secrecy, due to the linear model of innovation they generally adopted.

In the early 1980s, as a prime reaction to the weak form of protection and the increasing role of venture capitalism, new firm entries increased dramatically. Small Medium Enterprises (SMEs), that were often seen as non-threatening started a wave of creative destruction. This wave led to what is coined 'The third industrial revolution' (Fagerberg, 2005). Radical products that primarily depended on specialized knowledge, created a new breed of firms. Firms that were knowledge driven managed to threaten the existence of large well established, incumbent firms. This turbulent, extremely dynamic environment is a key characteristic of new, HT industries compared to LMT mature industries. This somehow independent rise of the HT sector, created a sector that has distinguished, unique characteristics if compared to the classical LMT sector. At the beginning of its rise, the HT sector was subcontracted to serve major governmental projects. Later, due to the convergence of technologies and the rise of standards, the applicability of HT products became wide, and covered all non-governmental contracts and sectors. As a result, bidirectional dependability emerged between HT and LMT, where the former became the supplier of the later. To put it simply, the HT sector took the role of the main supplier, and the LMT sector the user's role.

LMT is classically regarded a lagging sector in terms of growth, innovation and various other economic indicators. Recent studies, however, demonstrated that LMT is currently witnessing a major renewal and strategic shift. In the year 2000, the OECD (2003) reported that the Low Technology (LT) sector alone, contributed to more than 32% of global manufacturing exports (Mendonca, 2009). Growth in LMT is highly noticeable. For instance, in 1969, the total production of machine tools represented 9M$ (Liu and Brookfield, 2000). In 2006, according to Gardner Publications (2007), this amount has reached 3.7B$ (Chen, 2009).

Our results suggest a renewal in LMT accompanied by further adjustments in HT firms' strategy both in the firm and external to the firm levels. The paper is organized as follows; Section 1 includes a short review of the pertinent literature, the theoretical framework and the research hypotheses. Section 2 presents the survey data, the methodology used, the selection of variables, how they relate to the research hypothesis and the theoretical framework. After, the paper explores the primary results in Section 3, and is followed by a detailed discussion that includes the validation of hypotheses and implications from the results in Section 4. Section 5 concludes with future research work projected.

3.3 Theoretical Framework and Research Hypotheses

The theoretical framework of the paper will address various factors divided into two groups. The *first group* of factors is firm specific and the *second group* addresses external factors (with respect to the firm). The first group will include: the firm's strategy, absorptive capacity, technology and knowledge management processes. The second group will include the influence of customers, universities and government as external entities to the firm. Figure 3.1 shows the conceptual framework, based on which hypotheses are developed. The study will be carried out on the firm level and the two views (from within and outside the firm) are presented. Figure 3.1 shows the interactions and dependencies between the different agents considered in the theoretical framework.

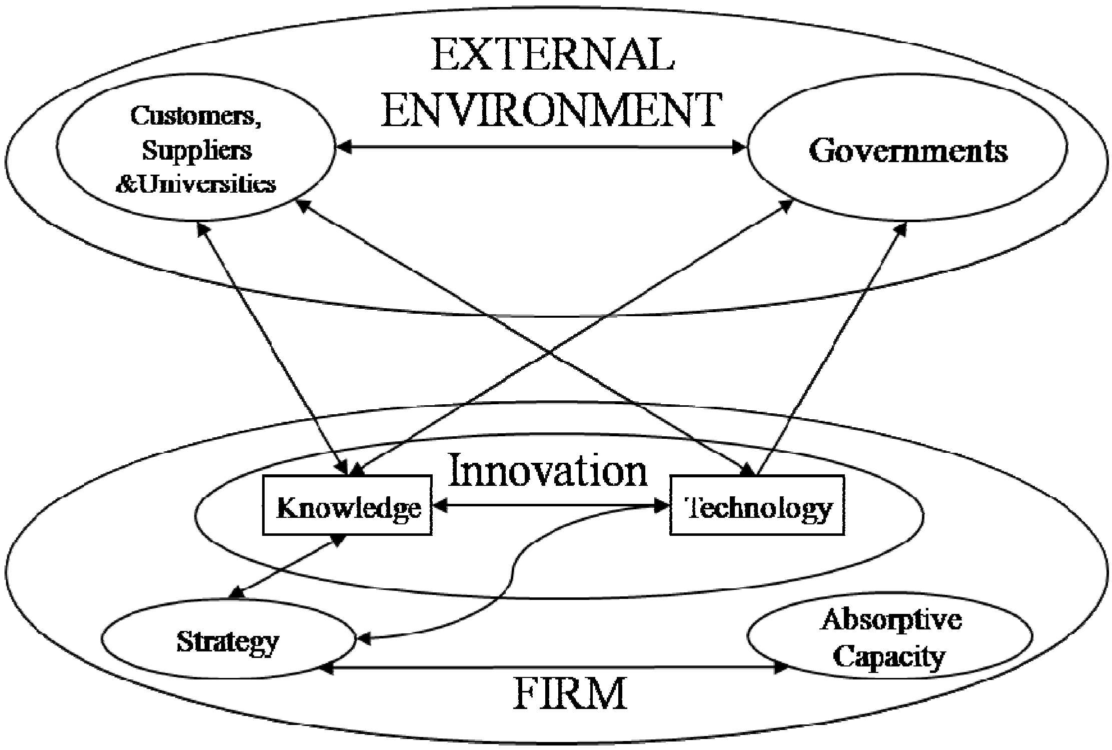


Figure 3. 1 Conceptual framework

3.3.1 Firm specific factors (from within)

3.3.1.1 Strategy

LMT firms are traditionally focused on cost based strategy. This mature sector has already developed its major breakthrough innovations and capitalized on them. Later, the sector was primarily focused on enhancing the manufacturing and services processes altogether. With severe price competition, firms fighting for survival in that sector have started to shift their strategies from cost driven strategies towards differentiation strategies (Robertson et al., 2009; Von Tunzelmann and Acha, 2005). Differentiation is carried out by putting more focus on product quality and enhancing the manufacturing process, while maintaining competitive prices. Classical examples include, the use of software programs to control manufacturing tools, and the use of database programs to manage inventory, in manufacturing facilities. As a result, firms in LMT created a demand to the HT sector to provide them with the necessary technologies. This is a phenomenon that created a sort of dependability between the two sectors, LMT as the user, and the HT serving as the supplier. This dependability was not evident in the early 80s when the third industrial revolution was still in its early beginnings. This strategic renewal on the firm's level is due to two main factors. The first is the maturity of certain technologies provided by HT that could be exploited by LMT firms. The second is the nature of those technologies that are generally fit for deployment in LMT. This category of technologies was labelled 'General Purpose Technology' (GPT). GPT is defined as a technology that helps change, in a radical way, existing technologies (Freddi, 2009). GPT is classically the output and the maker of industrial revolutions. For instance, the steam engines, chemical radical innovations, ICT products are all considered GPT. The HT is the product of the third industrial revolution, characterized by producing GPT (Fagerberg, 2005). The ICT for instance is constantly explored by LMT to enhance its information systems, and is an example of a GPT. It is important to note that General Purpose Technologies (GPT)s are technologies that have the ability to spill out of their home industries to other older industries (Von Tunzelmann and Acha, 2005). Consequently, technologies defined as GPTs "Often have the properties of being able to become pervasive, through their take-up in one industry after another" (Freeman and Perez, 1988; Freeman and Louca, 2001). Industries able to drive that kind of dynamism are therefore considered GPTs (Helpman, 1998). As a result, it can generally be considered that ICT is considered a GPT. This is evident from the innovation that ICT spills over from its own sector to other classical LMT sectors that are heavily dependent on their own products. ICT managed to diffuse in almost all sectors in our society that range across the various low and medium technologies like textile, chemicals, automobile manufacturing and so on. Those industries adopt the various ICT products (such as software, hardware, telecommunication equipment) in their manufacturing process.

HT firms are usually focused on differentiation and focus (Viardot, 2004). This is natural since those firms' main competitive advantage is to provide superior technologies, to serve other sectors (including the LMT). Consequently, unlike the LMT that is cost centred, HT firms focus on R&D investment, and protecting their innovative ideas. Differences in firm objectives across the two sectors, is definitely a key factor influencing the variability of strategy formulation and execution. This brings us to our first hypothesis relating to firm strategy:

H1: Firm Strategy: Firms in HT follow a combination of focus and differentiation strategy, while firms in LMT are cost focused. Firm in HT are product innovation focused, while in LMT firms are process oriented (Ghosal and Nair-Reichert, 2009; Santamaria et al., 2009; Heidenreich, 2009).

3.3.1.2 Absorptive capacity

The firms' ability to identify, activate and manage external sources of knowledge for success is what is generally referred to as the firm's absorptive capacity (Cohen & Levinthal, 1990). Increasing a firm's absorptive capacity increases its awareness of market and technological trends. This assists in predicting future development, engages into various forms of innovation through the combination of various accumulated knowledge. As a result, search strategies should align with a firm's own absorptive capacity. In LMT, a generally stable industry, innovation success is dependent on firms' absorptive capacity focused on the market input (from customers and competitors). In contrast, innovation success for HT firms is dependent on the absorptive capacity focused on deep technological knowledge and expertise (Grimpe & Sofka, 2009).

On the one hand, LMT firms enhance their absorptive capacity by hiring resources that support the firm's search strategy, focused on market input. Resources usually include personnel with generalist profiles, in the various financial and technological areas. For instance, on the technological side, when studying Taiwan's machine tool industry, Chen (2009) found that the industry depended heavily on trained engineers. Those engineers were the principal ingredients of their firm's absorptive capacity. Furthermore, they were key elements in the knowledge transfer process. On the other hand, HT firms, whose core competitive advantage is technological superiority, are expected to be more focused on highly technical staff with deep technological knowledge in their field of expertise. This dependability is obvious when examining the market mobility trends, and the way HT firms attract highly trained, research oriented technical resources in their R&D departments. That in mind, we state our second hypothesis on absorptive capacity as:

H2: Firm Absorptive Capacity: In HT, firms are gradually accumulating knowledge from within, while firms in the LMT benefit more from external collaboration and interactions. Furthermore, firms HT search strategy should be better due to their more efficient absorptive capacity (Grimpe & Sofka, 2009).

3.3.1.3 Technology, Knowledge and R&D management

Technologies can be developed in house, or acquired. Let us first examine technology acquisition. Technology acquisition can take several forms: through the use of Mergers and Acquisitions (M&As), Licensing Contracts (Inward Technology Licensing-ITL), formal or informal cooperative modes of R&D together with collaborative networks agreements on technology activities (Tsai & Wang, 2009). ITL's main characteristics are: helping a firm to lower its cost and allocate extra focus on marketing its own technologies; facilitate technology acquisition, since the supplier might not be willing to sell the technology; decreased competitive advantage, since other firms could be using the same technology (Zahra et al., 2005). It was however found by Tsai and Wang (2009) that ITL does not significantly contribute to a firm's performance in LMT. The main difficulty referred to by the authors is the integration between old and new technologies.

According to Tsai & Wang (2009), outsourcing and licensing technologies might penalize technological innovation. First, firms should clearly identify their core competitive advantage to choose the right suppliers. If not, firms run a high risk of inefficiently utilizing their outsourcing and licensing agreements. Second, the misidentifying of potential technological problems can clearly lead to false choice of patents rights. As a result the technological integration process is mismanaged. Finally, firms might be lacking expertise in outsourcing activities. As a result firm's absorptive capacity should be properly engineered to ensure the maximum gains from technology transfer and acquisition especially if the knowledge acquired is complex and tacit. As external technology acquisition triggers organizational learning, the absence of firm's internal knowledge process development is an obstacle. As prior in-house R&D increases a firm's absorptive capacity, in turn it enhances the external technology acquisition process.

In LMT, firms are highly dependent on externalizing knowledge intensive processes. This is primarily due to two reasons. First, the daily nature of the knowledge needed is generally not intense and is often centred on process innovation. Therefore, even with the internalization of technology development, the return on that form of in housing is humble. Second, in the case where highly intense knowledge is needed, externalizing the development, through one of the externalization mechanisms if obviously more economic. As a result, firms in LMT traditionally seek knowledge from identifiable, limited sources from experts in their industries that are usually HT. For this reason, technological competitive advantage decreases, since competitors absorb the same knowledge from the same sources.

Externalization necessitates technology fusion. Technology fusion is the integration of the various sources of knowledge to produce one technology (Kodama, 1992). In his study, Freddi (2009) excludes the role of IT in the fusion process based on the fact that IT is regarded in LMT as a separate body of knowledge. Accordingly, the use of IT as an example of GPT in LMT should be ignored. This statement cannot be generalized for all segments of IT, where for instance it neglects the role of open source software that can allow changes to its core architectures and embodiment of knowledge in its core functions. Consequently, it could be argued that the role of IT, as a product of HT in LMT is evident, both to enhance process innovation and to serve as a fusion medium to the various technological sources in the LMT. This brings us to our third hypothesis on technology:

H3: Firm Technology: In HT, firms are generally focused on developing GPT, with high modularity. In contrast, firms in LMT are focused to produce systemic products and technologies, based on technologies offered from suppliers.

As a result, interdependence occurs between the two sectors, where LMT generates the demand and HT acts as a supplier that fulfils it. This inter-dependability is of significant impact on both sectors. For instance, if LMT decreases its demand, HT will suffer a tremendous decrease in its revenues, putting at risk its in-house R&D. And since the LMT is generally positioned as a user

(Robertson & Patel 2007), and the HT as the producer, LMT could be seen as one of the main factors influencing the HT innovation diffusion process. Therefore, an increasing technological adoption by the LMT, results in higher diffusion rates for the HT innovation. The ability of the LMT sector to diffuse innovations enhances its capability of adapting the innovations to their internal use. In the same vein, this puts more pressure on HT to produce configurable, modular products to markets. This phenomena of adaptation of configurable products, added more to LMT price competition wars. It enabled the sector to compete on design, functionality and quality (Sanatamaria et al., 2009).

This shift and renewal phenomena occurring at the LMT firm level is motivated by the increasingly sophisticated tastes driven from international expansion, while maintaining high standards for safety and regulations provided by international and governmental regulators. This can be witnessed in the Food, Drink and Tobacco (FDT) industry. For instance, in studying patenting activities, Mendonca (2009) found that the Food, Drink and Tobacco (FDT), is witnessing an unprecedented growth in patenting activities. This recent growth is explained by the change in tastes due to the internationalization of the industry, where tastes became more complex, diversified and with the general directive of enhancing the standards for safety and regulations. Generally it was found that patents have a stronger impact on firms in HT than in LMT, and that the effect of the patent portfolio size is highest in HT, compared to that of the LMT. However, Lichtenthaler (2009) found that the quality of the patent portfolio is higher in the case of HT than that of LMT.

Patenting is one way of appropriating firms' R&D investments. The OECD classifies industries according to the percentage of investment in R&D with respect to turn over. According to OECD (1994), HT firms are generally investing more than 5% in R&D, while LMT less than 5% and LT invest less than 0.9% in R&D. This typically low investment in R&D explains the LMT's low intensity of R&D and the marginalized importance of knowledge appropriation through patenting, like that found in the paper industry (Ghosal & Nair-Reichert, 2009). This in turn has affected the likelihood of the LMT sector to bring any radical innovations, and increased its propensity to further invest in process innovation, more tied to learning by doing, or learning by using (Lundvall,1988) or further including learning by interacting, learning by producing and learning by searching (Lundvall & Johnson, 1994). This is confirmed by Chen (2009) who shows that the main value creation in LMT is primarily due to craftsmanship, learning by doing, training and experimental knowledge. This is a contrast to the HT that is mainly focused on radical innovation and formal R&D activities.

When considering knowledge, apart from technologically specialized firms, customers generate ideas and solutions that are tightly integrated with the problem being faced. Their knowledge is tacit and is difficult to evaluate. In contrast to customers, R&D organizations and universities are extremely theoretical and their knowledge is usually a bit distant from the application. As a result, firms in HT are always faced with adaptation issues when using university based knowledge. Despite this adaptability requirement, it is found that collaborating with R&D institutions is more likely to exhibit a higher degree of innovativeness, a reason why HT are the main beneficiary of the explicit knowledge developed by formal ties with universities and research labs. Due to tacit nature of the knowledge circulated, LMT firms use imitation strategies with a leakage risk. In that context, suppliers are a considerable source of knowledge, providing various components of the final product (Grimpe & Sofka, 2009). Consequently, firms in LMT seek market knowledge and are more inclined to follow the open innovation model, while HT generally follows the linear model of innovation where the R&D is the main seed of innovation in that sector.

This externalized vision of knowledge acquisition broadens the scope of knowledge search (Grant, 1996), as in LMT. However, it does not allow the necessary depth of knowledge search to create unique radical technologies. This is a contrast to HT that is characterized by the necessary breadth of knowledge search to diversify its technological frontier, together with the required depth, to provide distinguished breakthrough innovations. This mix of breadth and depth search distinguishing the HT differentiates the sector with a remarkable return on R&D. Depth and breadth search strategies can be found in the work of Laursen & Salter (2006), Katila and Ahuja (2002) and Grimpe & Sofka (2009). Our fourth, and last, hypothesis of the section is thus:

H4: Firm Knowledge: In HT, the primary source of knowledge development is internal, and from collaboration with research institutes and universities. Patenting activities are the form of formal R&D output for HT. For LMT, the primary source of knowledge development is from collaborating with customers, and suppliers (Santamaria et al., 2009; Tsai and Wang, 2009). This form of collaboration in LMT encouraged learning by doing and learning by using (Lundvall, 1988).

3.3.2 External to the firm factors (from outside)

Chesbrough's (2003) open innovation model emphasizes the role of external actors to enhance a firm's innovation performance. There are four identified interconnected factors by Chesbrough (2003) that push toward the direction of open innovation: increasing mobility and availability of skilled workers, venture capital market making funds available for entrepreneurs, external options to introduce new ideas, increased capabilities of external suppliers. The first two points characterize the HT sector, whilst the two later address the LMT sector.

On the one hand, various studies focusing on industrial clusters have identified various factors that lead to such agglomerations. The increased mobility of skilled workers has certainly increased the competitive advantage of the various clusters in different continents. As initiated by Saxenian (1994) in Silicon Valley, this can be witnessed in Ottawa, Montreal, Cambridge, etc. This availability of skilled workers has been found to be attributable to the proximity of universities, competitive and complementary firms, in the firm's own cluster. The majority of those relatively new clusters were dominated by HT sectors, which often include telecommunication, biotechnology and aerospace. Furthermore, a number of studies like that of Niosi (2003) have targeted venture capital and how it motivates innovation in the various clusters, and examples are extremely wide for HT firms that depended heavily on venture capital to grow from a small size to a large enterprise.

On the other hand, this informality in knowledge transfer and production added to the dependability on external agents as users with complex demands has contributed positively to the various LMT industries such as the automobile industry (Carlsson, 1995; Chen, 2009). These interactions between LMT and complex users' demands increased the competence of LMT, through the various means of learning, and problem solving techniques addressing complex users' needs. The constant interaction between LMT firms and their clientele not only affected mastering technological 'process innovation', it also developed those firms' market intelligence, learning from their customers the latest technological and market trends. These issues raise the next four hypotheses concerning customers, suppliers, universities and competitors:

H5: Customers: HT firms are serving customers with more complex needs, while LMT firms depend on their customers to provide expertise about product's operation. Furthermore, it is expected that LMT would be relying on technologies produced by LMT. Technologies offered by

HT to LMT are modular products to fit their existing environment. Therefore, technologies acquired by LMT customers are developed to fit operations of other technical systems.

H6: Suppliers: In LMT, knowledge and technologies are acquired through interaction with external entities, such as suppliers and customers. HT firms are less dependent on suppliers then their peers from LMT (Chen, 2009; Heidenreich, 2009). While HT could be seen as entrepreneur dominated, the LMT is supplier dominated. H6 aims at confirming Pavitt (1984) taxonomy.

H7: Universities: In HT, firms depend more on collaboration with universities, than LMT. Consequently HT firms are expected to bring intensive knowledge in the academic fields.

H8: Competitors: HT firms depend less on collaborating with competition than the case of LMT.

The role of government is historical, and unique in the development of HT. This role does not have the same effect on LMT at present. One reason is that governments are mainly focused on industries that provide higher returns on investment, higher GDP and employment rates. While there is evidence of the failure of government to directly provide innovation to the industry, the supporting role of government in Taiwan has measured a success (Chen, 2009). This brings us to our last hypothesis on the role of government:

H9: Government: Governments are more focused on the HT due to its economic benefits. Consequently, governments offer HT firms more resources and more tools to regulate and protect firms' technological edge. This focus is expected to be less for LMT.

Of course, hypotheses from "within" (H1 to H4), and from "outside" (H5 to H9) are full of commonalities that are complementary in nature as will be seen in Table 3.1. The purpose here is to give a clear picture of the interaction between the firm and its environment. This interaction in our view is based on knowledge sharing, and technology acquisition between the various entities in the model presented in figure 3.1.

3.4 Data, Variables and Methodology

3.4.1 Data

A survey questionnaire was sent to more than 900 firms (in the scope of project MINE) of which 736 were considered in our analysis. The questionnaire targeted five areas addressing the context of innovation of the firm in its own sector. The first regards the nature of customers and their needs. The second focuses on the nature and extent of scientific and technical knowledge production. Thirdly, the factors that influence innovation at the firm's own sector are examined. The fourth presents the resource inflows and growth in the sector. Fifth, the firm's strategic and competitive dynamics in its own sector is explored. The answers are based on a Likert scale from 1 to 7. At one end, 'one' denotes that the respondent 'totally disagree', at the other end, 'Seven' implies a 'totally agree' response. The details and description of each factor in the corresponding area is explained in the next section.

The study is thus based on firm level data. All firms are sorted according to their primary activity, and are also confirmed by their North American Industry Classification System (NAICS). The questionnaire is targeted to firms in various industries, and countries. Countries include Canada, China, USA and others accounting for 20.8%, 19.8% and 14.9% respectively of the total sample size. Industries include all high-tech firms such as the ICT (including telecommunication and information technology firms), pharmaceuticals and biotechnology as well as aerospace accounting for 56%, 31% and 13% respectively. All other sectors are identified as LMT in our analysis, they include manufacturing, automobile industry, pulp and paper as well as services (including banking, insurance and consulting services) accounting for 12.5%, 7.3, 7.1% and 72% respectively. In our database, the HT consists of 273 firms, and LMT of 463 firms.

3.4.2 Variables

This section presents the variables and how they contribute to the validation of our research hypotheses. Table 3.1 highlights how each entity presented previously in Figure 3.1, is linked to our research questions. Of course each variable responds primarily to one or more research question, and provide us indirectly with complementary information about the rest of the questions. The resulting matrix is presented in Table 3.1.

Please note that in table 3.1, each axis, has multiple variables. Each variable primarily addresses one of the entities in the conceptual framework marked in bold with a bold '**x**'. A variable can give indications regarding other variables and other hypotheses too, and this is marked with a regular 'x'. The name of the variable is composed as follows 'a_Hb', where 'a' is the primary entity\variable, and 'b' refers to the hypothesis number.

Customers: Firms in the survey were asked about the nature of their customers and their needs. Two questions were asked regarding this issue assessing: first, to which extent customers provide a significant expertise about how the firm's products operate (Cust_Expert_H5). Second, firms were asked to identify the complexity of customers needs (Cust_Need_H5).

Government: Firms are asked on the role of regulatory approvals to commercialize their technologies (Gov_Regu_H9). Firms were later asked whether time and resources are needed to obtain regulatory approvals, and whether this process prevents the imitation process (Comp_Regu_H8). Furthermore, the question of how intellectual property protection facilitates the value captured from innovation is also considered (Comp_Val_H8). The last question addresses whether the government allocates sufficient resources for firms to perform R&D and innovation in general, or not (Gov_Res_H9).

Table 3. 1 Linking Variables to Research Hypotheses

Axis	Variables	Cust.	Gov.	Sup.	Comp.	Univ.	Know.	Tech.	Strategy	Ab. Capacity
Customers	**Cust_Expert_H5**	**x**					x		x	x
	Cust_Need_H5	**x**					x	x	x	x
Knowledge	**Univ_KnowInt_H7**					**x**	x			x
	Univ__KnowCont_H7					**x**	x		x	x
	Sup__Know_H6			**x**			x	x	x	x
	Know__Firms_H4						**x**			x
	Know_Tech_H4			x			**x**	x	x	
	Know__Depend_H4						**x**	x		
	Know_Grad_H4						**x**			x
Factors Influencing Innovation	**Gov__Regu_H9**		**x**							
	Comp_Regu_H8		x		**x**				x	
	Comp_Val_H8		x		**x**		x	x	x	x
	Tech_GPT_H3							**x**		
	Sup_Tech_H6			**x**					x	x
	Sup__Ext_H6			**x**			x	x	x	x
	Sup__Trans_H6			**x**			x		x	x
	Strat__CostScale_H1								**x**	
	Strat_ProdProc_H1						x	x	**x**	
	Strat_Cost_H1						x	x	**x**	
Resource inflows and Growth	**Gov_Res_H9**		**x**				x	x		
	Strat_Fund_H1								**x**	
	Strat_Sales_H1						x	x	**x**	x
	Strat_Niche_H1						x	x	**x**	x
Strategy and Competition	**Comp_Change_H8**				**x**		x		x	
	Comp_Prod_H8				**x**		x	x	x	
	Tech_Speed_H3						x	**x**	x	
	Strat_Trans_H1								**x**	
	Tech_Sect_H3						x	**x**		
	AbCp_H2						x		x	**x**
	Comp_Rival_H8				**x**				x	
	Comp_Advant_H8				**x**		x	x	x	
	Comp_CostSub_H8				**x**				x	

Supplier: Firms are questioned about whether their new technologies are built on the latest technologies of firms in the sector. Two questions address whether the firm use different technologies in their own products (Sup_Know_H6), and if the operation of the firm's product relies on other technical system operations (Sup_Tech_H6). Finally two questions will address the external environment to the firm (Sup_Ext_H6) and how it forces unpredictable transformations (Sup_Trans_H6).

Competition: Competition is explored from various angles. First, a question is asked whether interactions between the various firms in the same sector result in new technological knowledge (Know_Firms_H4). Second, a firm is asked whether the appropriation of knowledge succeeds in minimizing the imitation strategies by firms (Comp_Regu_H8), and whether seeking this kind of appropriation sustain the firm's efforts to capture value from innovation (Comp_Val_H8). Furthermore, firms were asked various direct questions with respect to their competitors. One area addresses the frequency of entry of rivals due to new innovative products (Comp_Advant_H8), and its effect on the pace of technical change in the firm's own sector (Comp_Change_H8). The rival position versus incumbent firms is further explored (Comp_Rival_H8), and whether those dynamics erode incumbent advantages including lost cost substitutes or not (Comp_CostSub_H8).

Universities: The role of universities is explored by two direct questions, the first addresses whether the knowledge production process in the academic domain is intense and addresses directly the need of the firm in its own sector (Univ_KnowInt_H7). The second addresses the contribution of the firm and its sector to academic research via papers, data and research ideas (Univ_KnowCont_H7).

Knowledge: Knowledge is addressed in various questions in the survey. In terms of knowledge production, questions are addressed to firms on whether their knowledge is the result of accumulation inside the firms (Know_Grad_H4), or as a process of externalization by interactions with other firms (Know_Firms_H4), customers (Cust_Expert_H5 and Cust_Need_H5), or universities (Univ_KnowInt_H7 and Univ_KnowCont_H7). Knowledge appropriation is also addressed, as well as its effect on firm's strategy. Of course since knowledge touches every entity in our model, secondary information could be derived from most of the questions. For instance, asking about the utilization of cost reductions to increase the scale of operations implies that this demands a specific type of knowledge but the question does not address knowledge directly. Therefore, in table 3.1, knowledge (as a vertical category) is marked for most of the questions when another part of the table addresses knowledge directly (as an axis in its own right). The relation between knowledge and technology is examined by the variable Know_Tech_H4 and Know_Depend_H4 tests dependability.

Technology: Technology can be investigated as an embodiment of knowledge. Therefore the majority of questions addressing knowledge will to some extent touch technologies as well. However, technologies are addressed directly in three main areas, integration (Sup_Ext_H6), modularity (Sup_Tech_H6) (Sup_Trans_H6), and its identity as a general purpose technology (GPT) (Tech_GPT_H3) for some sectors. Consequently, whether the technologies produced by the firm are used by a wide variety of applications are of interest, notably to distinguish firms producing GPT from those that do not. Questions addressing the above are captured from 4 different questions in the axis labelled ‘Factors influencing innovation’.

Strategy: Strategies shape and get shaped by the various factors included in figure 2.1 and the reason for these strategic directives can be sensed from the majority of factors presented in table 1. The main 3 general strategies firms would follow are: cost (Strat_CostScale_H1) (Strat_Cost_H1), differentiation (Comp_Prod_H8) or focus (Strat_Niche_H1). From an innovation perspective, product and process innovation (Strat_ProdProc_H1), linear or open model of innovation could be added in the strategic orientation of the firm.

Absorptive Capacity: The well being of absorptive capacity is examined through a question to firms addressing their knowledge about significant developments in their own sector. This indicates the firm’s ability to search for knowledge (AbCp_H2).

3.4.3 Methodology

This paper tests for the equality of means between HT and LMT. The original sample size is 273 for HT firms, and 463 for LMT firms. To assure the consistency of results, given the inequality of the sample size, the 463 sample is divided into two random samples of 273 (Split half 1) and 190 (Split half 2) firms. Consequently, the same tests that are conducted on the original samples are also executed on the divided LMT sample (Split half 1 and Split half 2) with respect to HT. This methodology will help identify any discrepancy resulting from the different sample sizes with respect to test’s results and implications. The results are included in Table 3.2 across all three samples will ensure the conformity of results.

In order to use the t-test for different sample sizes, we should first analyze the data to test if the two samples follow a normal distribution. Common tests for normality of data are the kurtosis, and skewness test. The values of kurtosis and skewness are found to be around ‘0’ and are in the interval [-1, +1]. Therefore data is normally distributed. Consequently, Levene’s test is used to test the equality of variances, between the two samples. In the Levene test, if $p \leq 0.05$ then the t-test for unequal variances and unequal sample size is used. If $p > 0.05$ then the t-test for equal variances and unequal sample size is used.

Table 3.2 presents the results of the t-tests for equality of the means between HT and LMT and are analysed in the next section. Results from the t-tests illustrate the significance of the results by a 2 tailed representation. Consequently, the resultant of the 2 tailed representations is divided by two to ensure the interpretation on a one tailed scale. Those are the values presented next to each factor in Table 3.2. In Table 3.2, non significant p values are labelled (NS) and are shadowed. This presents in general, which factors were consistent across the three samples, and which were not. In the ‘Split Half 1’ and ‘Split Half 2’. NS factors are highlighted similarly. For each of the three samples (Original samples, Split half 1 and Split half 2), the first column represents the mean response for the HT sector, the second column represents the mean response for the LMT sector, the third column shows the p-value of the test for equality of the mean and the fourth column shows the significance in terms of stars, four stars being the most significant.

3.5 Results

For *Customers*, according to the analysis of means, all three tests support the fact that HT firms dominate LMT firms in the complexity of customer needs (Cust_Need_H5). This is however false when customers offering expertise to firms are examined (Cust_Expert_H5). In Split half 2, the difference is not significant for the sample of 190 firms. From that, we can primarily highlight that HT firms are serving more complex clients than that of LMT firms. However, firms in both sectors are closely aligned with their customer needs. For *knowledge*, findings demonstrate that

HT is much more dependent on explicit knowledge resulting from research labs and universities, if compared with the LMT (Univ_KnowInt_H7 & Univ_KnowCont_H7). This reveals the close relationship between HT firms and universities and academic institutes, and their dominant reliance on the classical linear model of innovation. Seeking new knowledge, compared to the LMT, firms in HT benefit tremendously from interactions between the various firms in their own sectors (Know_Firms_H4). Systems integration and modularity are more intense in HT than in LMT (Sup_Ext_H6 & Sup_Trans_H6). Consequently the dependency on suppliers is high compared to LMT (Sup_Tech_H6). One striking result is the significant difference between LMT and HT when the firm is asked about is reliance on the same stable technological base. LMT relies far more than HT on a stable technological base (Know_Depend_H4). This shows the dynamic nature of HT compared to the technologically mature LMT. Another, consistent result is that firms in both sectors produce knowledge based on gradual internal accumulation of experience (Know_Grad_H4). All results are consistent for all factors in the three comparisons. This highlights the consistency of all finding resulting from this knowledge axis.

Factors influencing innovation in the firm's own sector provide interesting results. First, it was expected that HT will advance the LMT sector when comparing the importance of regulatory approvals. Our findings suggest that LMT and HT both seek regulations (Gov_Regu_H9), and that regulations limit imitative strategies in both sectors (Comp_Regu_H8). Those results confirm recent findings that suggest that LMT firms are currently seeking regulatory approval ever more than before due to, for instance the more aggressive health regulations imposed by governments and the international communities. Those findings are consistent across the variants of the sample, suggesting certain robustness. HT, as expected, showed higher deployment of intellectual property protection (Comp_Val_H8). HT firms are more likely to capture value from innovation using IPs than their peers in LMT. In terms of modularity, integrations, interconnectivity, results of HT exceeds that of the LMT (Sup_Tech_H6, Sup_Ext_H6& Sup_Trans_H6), supporting the previous argument that suppliers in the HT are actually integrating various components into their products and hence depend on their suppliers in the process of product development.

Axis	Variables	*ORIGINAL SAMPLES*				*SPLIT HALF 1*				*SPLIT HALF 2*			
		HT	**LMT**			**HT**	**LMT**			**HT**	**LMT**		
		N=273	**N=463**	**P/2**		**N=273**	**N=273**	**P/2**		**N=273**	**N=190**	**P/2**	
Customers	**Cust_Expert_H5**	5.22	4.94	0.0065	***	5.22	4.89	0.0065	***	5.22	5.01	0.0590	NS
	Cust_Need_H5	5.81	5.20	0.0000	****	5.81	5.13	0.0000	****	5.81	5.29	0.0000	****
Knowledge	**Univ_KnowInt_H7**	4.95	4.41	0.0000	****	4.95	4.36	0.0000	****	4.95	4.50	0.0010	****
	Univ__KnowCont_H7	4.79	4.12	0.0000	****	4.79	4.07	0.0000	****	4.79	4.20	0.0000	****
	Sup__Know_H6	5.57	4.79	0.0000	****	5.57	4.79	0.0000	****	5.57	4.78	0.0000	****
	Know__Firms_H4	4.70	4.29	0.0000	****	4.70	4.30	0.0010	****	4.70	4.28	0.0015	***
	Know_Tech_H4	4.84	4.47	0.0005	****	4.84	4.46	0.0010	****	4.84	4.48	0.0045	***
	Know__Depend_H4	4.26	4.70	0.0000	****	4.26	4.74	0.0000	****	4.26	4.64	0.0055	***
	Know_Grad_H4	5.38	5.38	0.4630	NS	5.38	5.38	0.4730	NS	5.38	5.37	0.4615	NS
Factors Influencing Innovation	**Gov__Regu_H9**	4.57	4.46	0.2355	NS	4.57	4.47	0.2870	NS	4.57	4.44	0.2440	NS
	Comp_Regu_H8	3.89	3.76	0.1695	NS	3.89	3.77	0.2170	NS	3.89	3.74	0.1980	NS
	Comp_Val_H8	4.77	4.17	0.0000	****	4.77	4.20	0.0000	****	4.77	4.11	0.0000	****
	Tech_GPT_H3	5.21	4.69	0.0000	****	5.21	4.68	0.0000	****	5.21	4.71	0.0005	****
	Sup_Tech_H6	5.66	5.16	0.0000	****	5.66	5.15	0.0000	****	5.66	5.17	0.0000	****
	Sup__Ext_H6	5.84	5.37	0.0000	****	5.84	5.43	0.0010	****	5.84	5.29	0.0000	****
	Sup__Trans_H6	5.35	4.89	0.0000	****	5.35	4.93	0.0010	****	5.35	4.83	0.0005	****
	Strat__CostScale_H1	4.99	5.03	0.3650	NS	4.99	5.16	0.0985	NS	4.99	4.85	0.1810	NS
	Strat_ProdProc_H1	4.13	4.44	0.0045	***	4.13	4.49	0.0030	***	4.13	4.36	0.0600	NS
	Strat_Cost_H1	4.79	5.13	0.0015	***	4.79	5.22	0.0005	****	4.79	5.00	0.0685	NS
Resource inflows and Growth	**Gov_Res_H9**	3.86	3.18	0.0000	****	3.86	3.19	0.0000	****	3.86	3.17	0.0000	****
	Strat_Fund_H1	3.51	3.10	0.0005	****	3.51	3.04	0.0000	****	3.51	3.18	0.0145	**
	Strat_Sales_H1	4.35	3.65	0.0000	****	4.35	3.70	0.0000	****	4.35	3.58	0.0000	****
	Strat_Niche_H1	4.72	4.10	0.0000	****	4.72	4.16	0.0000	****	4.72	4.02	0.0000	****
Strategy and Competition	**Comp_Change_H8**	4.98	3.77	0.0000	****	4.98	3.86	0.0000	****	4.98	3.65	0.0000	****
	Comp_Prod_H8	4.30	3.42	0.0000	****	4.30	3.42	0.0000	****	4.30	3.42	0.0000	****
	Tech_Speed_H3	5.06	3.78	0.0000	****	5.06	3.84	0.0000	****	5.06	3.70	0.0000	****
	Strat_Trans_H1	4.80	4.55	0.0120	**	4.80	4.70	0.2080	NS	4.80	4.32	0.0005	****
	Tech_Sect_H3	4.81	4.19	0.0000	****	4.81	4.33	0.0000	****	4.81	3.98	0.0000	****
	AbCp_H2	4.32	3.89	0.0000	****	4.32	3.96	0.0040	***	4.32	3.80	0.0000	****
	Comp_Rival_H8	5.17	4.95	0.0185	**	5.17	4.92	0.0215	**	5.17	4.99	0.0815	NS
	Comp_Advant_H8	4.55	4.49	0.3160	NS	4.55	4.46	0.2575	NS	4.55	4.53	0.4650	NS
	Comp_CostSub_H8	4.41	4.55	0.1375	NS	4.41	4.60	0.0970	NS	4.41	4.48	0.3265	NS

Note: ****, ***, **, * represent significance at the 0,1%, 1%, 5% and 10% levels respectively

Table 3. 2 t- test results (original samples and LMT split samples)

Moreover, technologies produced in the HT are used for a wide variety of applications. This confirms that HT, as a breed of the third industrial revolution, is producing general purpose technologies (GPT) (Tech_GPT_H3). Those results are consistent across all samples. Two out of three samples, confirm that LMT is much more concerned with cost reductions derived by increasing the scale of operations. However, all results are not significant. This result is interesting, since it demonstrates that HT is concerned with production scale exactly like scale intensive sectors. In the same vein, all samples confirm that most of the firm's products face several cost constraints, with only one non significant sample. This suggests that LMT firms are generally more cost focused (Strat_Cost_H1). HT firms also try to minimize cost by increasing the scale of operations (Strat_CostScale_H1). All samples confirm that LMT firms are more concerned with improving production process that finally brings higher returns that product innovation (Strat_Prod_Proc_H1). One of the three samples is however non significant.

Examining *resource inflows and growth*, results are consistent across all samples, and highlight that resource inflows and growth are more dynamic and dominant in HT than LMT. Results suggest that governments still allocate more resources to support R&D and innovation to HT (Gov_Res_H9). Dynamism in the sector, represented by entry of innovative start-ups that have easy access to funding far dominates in HT than in LMT (Strat_Fund_H1). Furthermore, sales grow significantly faster in HT than LMT (Strat_Sales_H1). This growth in sales is actually boosted by new niches, in a turbulent sector. This suggests that HT firms are following a differentiation and focus strategy (Strat_Niche_H1), compared to LMT that mainly focus on cost, and enhancing process innovation (Strat_Cost_H1).

Analyzing *strategy and competition* firms in HT are faced with a remarkable fast pace of change compared to LMT (Comp_Change_H8). In HT, rivals enter markets due to their innovative products (Comp_Prod_H8). Technological advancement accelerates at a very fast pace (Tech_Speed_H3). Results for Comp_Prod_H8 and Tech_Speed_H3 enormously differentiate HT from LMT, with the highest significant difference of means across all questions answers. In HT, external factors are forcing unpredictable transformations (Strat_Trans_H1). This result is not significant in Split Half 1. However we notice that the significance level is very small. This indicates that both LMT and HT are influenced by unpredictable transformations. The turbulence of the sector and breakthrough innovations are the major characteristics of the HT sector and the results are consistent for all samples. Competition is extremely severe in both sectors but slightly higher in HT (Comp_Rival_H8). Another important result is related to low cost substitutes (Comp_CostSub_H8); all results across all samples, are non significant for that factor. However in all samples, LMT is slightly higher than HT firms. This suggests that LMT still is focusing on cost; however HT too is facing severe cost substitution attacks. Finally the results concerning the variable AbCp_H2 suggest that HT have a better knowledge search strategy than LMT, indicating a more coherent and efficient absorptive capacity.

3.6 Discussion

This section will revisit our hypotheses and verify whether they were validated by our analysis.

3.6.1 From within

H1: Strategy: Results suggest that HT firms are still generally inclined towards more differentiation, while their peers in LMT are more inclined towards cost. Those results were however not of high consistent significance. On the one hand, firms in HT are seen to put considerable weight on cost reductions through increasing the scale of operations. Equivalently, the tests indicate that a good portion of LMT firms are realizing the importance of product innovation compared to process innovation, while there is a considerable reference that differentiation and product innovation dominate in HT, and that cost focus and process innovation dominate LMT. Those results are not consistent across all samples, and sometimes are not significant. Consequently, results are implying major strategic shifts and are pointing towards a renewal process in both sectors. Firms in HT, while focusing on product and breakthrough innovation that are fundamental in differentiation strategies are also occupied with large scale operations to minimize cost. Those results are interesting, and their market proofs are numerous. Take for instance, Telecommunication Equipment Manufacturers (TEM). TEM firms are identified as HT, innovating and bringing products to market through product innovation. However the same firms are producing large scale production goods such as routers, multiplexers and others. It is obvious that firms in that segment of the industry, while focusing to bring new innovations to market, are getting more cost aware then they previously were. This new strategic shift combining a mix of differentiation and cost focus is one of the major strategic directives that those firms followed after the internet bubble boom in 2001.

On the other hand, LMT firms, which are mainly focused on process innovation and cost, are bringing new innovations to market and are aiming to differentiate their products. Recent literature confirms the shift towards differentiation but the majority of literature would still claim that LMT firms are still focused on process innovation. Those results are apparently opposing in principle, however they are complementary. Firms in LMT while seeking differentiation from other firms could seek the enhancement of their manufacturing process, and in that case they would seek process innovation. Those firms could also try to introduce new products to market in order further differentiate them from competition, increase market share, and enhance their profitability. According to our analysis, H1 is rejected.

H2: Firm Absorptive Capacity: Results suggest that firms in the HT sector are characterized with an extremely efficient absorptive capacity mechanism, if compared to LMT. Firms in HT are expected to have a higher ability to search for unexpected market trends. On the one hand, this distinguished configuration in HT enables firms to interact with various internal and external entities to absorb and develop technical knowledge. On the other hand, LMT firms seem on the contrary to be in the process of renewal, by building internally on a stable technological base, while firms in HT are still faced by unexpected market moves. This suggests that while HT firms are better equipped internally to develop knowledge, their external market interactions do not serve them well to predict unprecedented moves. According to our analysis, H2 is rejected.

H3: Firm Technology: Results suggest that HT is a prime producer of GPT compared to LMT. Those GPTs serve a wide variety of applications, are interoperable, modular and configurable. This explains the reason why firms in HT are aligned with their complex customer needs. According to our analysis, H3 is accepted.

H4: Firm Knowledge: Our results suggest that HT firms are more active externally than LMT. In the same vein, both sectors generate new knowledge from their gradual accumulation internally. Those results again highlight a strategic shift and renewal especially on the LMT side. On the one hand, results suggest that HT firms far dominate LMT firms in the collaboration with universities and production of explicit scientific knowledge. Consequently, HT firms are still highly dependent on the linear model of innovation. This domination of the linear model did not however nullify the importance of open innovation, where it is seen that HT firms still dominate knowledge production by interaction between firms. This is probably due to the HT firms' capacity to invest in appropriating their knowledge, an act that minimizes the risks related to collaboration. On the other hand, HT and LMT firms are also dependent on internal knowledge development from within. This is natural for HT, however apparently deviating from the results of recent literature that emphasizes the dependency of LMT on external links. We find this result logically satisfactory and in fact complement some recent finding on the performance of LMT firms. Recent literature, like Tsai and Wang (2009) demonstrates that while focused on the externalization of knowledge acquisition for LMT, however, they also emphasized the importance of internal knowledge development to build the firm’s absorptive capacity. It was found that, if LMT firms increased investments in internal knowledge capabilities, their absorptive capacity enhances, and this renders the externalization of knowledge more efficient and beneficial to the firm. This finding again highlights a transformation in the LMT sector. In this sector, firms are now more inclined to produce internal knowledge. This could be due to cost reason, or to minimize externalizations risks, and increasing differentiation. According to our analysis, H4 is rejected.

3.6.2 From outside

H5: Customers: HT firms are serving complex customers. This is a fact that is confirmed by our findings. Despite this complexity, both sectors are closely aligned with their customers. Our findings lead to a logical explanation: It is true that both sectors align almost equivalently with their customers, but for different reasons. On the one hand, firms in HT align to understand their client’s needs and hence produce more innovative products. On the other hand, LMT firms are there to learn from customers and probably test their products that they are not able to test internally due to financial constraints. Hence, H5 is accepted.

H6: Suppliers: If we take as a fact that, LMT firms are the clients of the HT ones, our results show that technologies produced by the HT fit a wide variety of applications. Those products are highly configurable and adaptable to fit the various customers’ demands. Consequently, we can deduce the LMT firms are supplier dominated, and H6 is accepted.

H7: Universities: HT firms are much more dependent on universities and explicit knowledge transfer than LMT. This finding suggests that HT firms follow the linear model of innovation. However, this dependability on the linear model, did not affect HT firms to equivalently consider open innovation. HT firms are seen very able to master the mix of the two strategies of innovation. Historically, HT firms are products of universities. This close relation with the academic research institutes, were not dropped facing market changes. In fact, this relation advanced, while adapting with the open innovation model to cope with the changing concepts of design, and modularity. Hence H7 is accepted.

H8: Competition: HT firms are still dominating external collaboration with firms, compared to LMT firms. This is probably due to the intellectual property protection that surrounds innovations of HT firms. Consequently the risk of external interactions is often less with HT than LMT. As a consequence, H8 is rejected.

H9: Government: In general Governments allocated much more resources to support innovation for the HT sector. Furthermore, intellectual property protection is much more often used to appropriate innovations for HT firms. Regulatory approvals are used by both sectors equivalently. This finding is interesting, and contradicts our primary hypothesis for LMT. This contradiction supports recent findings of Mendonca (2009) that suggest that LMT firms are currently seeking to appropriate innovation and that regulatory forces play a key role in that sector. Since the war of standards and regulatory forces has dominated HT for a couple of decades, regulation is dominating the LMT sector as well. So in general, governments are supporting the HT to produce more innovation and regulating the industry. In contrast, governments are not supporting the LMT equivalently, and are controlling the regulatory forces of that sector. This is driven by the increased public awareness for health, security and safety for LMT products. Our last hypothesis H9 is thus rejected as well.

3.7 Implications for Theory and Practice

On the theoretical level, one major implication of this transformation and renewal process is the OECD sectoral classification itself. This new transformation implies an expected increase of investment in the LMT sectors that are currently witnessing support to enhance their firms' internal R&D. This phenomenon will most likely change the definition of OECD of LMT. While generally, the OECD classifies high tech firms to be investing more than 5% of their turn over on R&D, an increase in that direction might lead to a shift from some of the medium-high tech firms to the high tech zone. In the same vein, with the current economic crisis, the cost awareness regime that HT firms are increasingly deploying, together with the tightening of internal R&D investment, the classically defined high tech firms that will cease to invest in R&D will probably slip to more of a medium tech industry, according to the OECD definition. If a leader-follower process emerged, together with a consistent flow of high tech firms reducing R&D investment, the whole sector might transform, and join a lower classification. This suggests the redefinition of the OECD to the sectors undergoing the renewal and transformation processes. Otherwise, we might witness high tech firms slipping into lower categories of sectoral classification.

In practice, the various agents presented in the paper will be affected by this renewal and transformation process. Universities that probably depended more classically on high tech firms for contracts might need to diversify their collaboration agreements to include low and medium tech firms. This necessitates that firms in LMT, which increasingly depend on internal research, increase their collaboration with universities so that it can provide the same role it does with the HT industry. High tech firms that are seeking to be more cost aware, however are least likely to change their innovation mix to increase their dependency on universities than internally, due to their cost minimization process. Furthermore, Governments that have once encouraged HT, should be more aware that HT might not be able to sustain and provide the same growth levels it once provided, and hence the encouragement of the LMT might be more helpful in order to increase economic growth, and decrease unemployment rates.

3.8 Conclusion and Future Research Work

A renewal and transformation is occurring to both the LMT and HT sectors. LMT is shifting towards differentiation, while HT is shifting towards cost focused strategy. Furthermore, HT firms that are proven to be generally following the linear model of innovation are equivalently utilizing the open innovation model. And firms in LMT that are generally conceived to be supplier dependent are shifting to produce internal knowledge. This renewal process did not misbalance the supplier, user role that HT and LMT play respectively. In fact our results show that LMT is still the user of the GPT that HT produces. Additionally, HT firms that are expected to have a more developed absorptive capacity sometimes fail to predict market transformations compared to their peers in LMT. In the same vein, LMT firms seem to be developing their internal technological arsenal that makes them capable to build on a stable technological base. Governments give more support to the HT. However, both sectors are equivalently under pressure from regulatory forces. This again reinforces our hypothesis that both sectors are going through a transformation and renewal phase.

The study at hand, has comparatively analyzed the two, HT and LMT sectors. The analysis has brought interesting results; some supporting existing literature and others that were not. The general picture confirms a transformation of both sectors. The HT sector, that often brought non traditional strategies to innovate and bring products to market, is also considering classical techniques used by the mature of industries of LMT. The LMT sector that is classically viewed as a lagging sector compared to the HT, is seeking non traditional strategies, such as more focusing on differentiation than cost, and focusing on internal innovation to increase it competitive advantage. Extending the analysis of the present findings, our future research work will include two additional dimensions to our current analysis. The first is a cross country analysis, and the second is across firms various sizes and structures. This in turn will deepen our current understanding of the transformation and renewal process that those two sectors are undergoing.

3.9 References

Bruland, K., Mowery, D., 2005. Innovation through time. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp. 349-379

Carlsson, B. (Ed.), 1995. *Technological systems and Economic Performance: the case of Factory automation*. Kluwer Academic Publishers, Boston

Chen, L., 2009. Learning through informal local and global linkages: The case of Taiwan's machine tool industry. *Research Policy* 38 (2009) 527-535

Chesbrough, H., 2003, *Open Innovation-The new Imperative for creating and profiting from technology*. Harvard Business School Press, Boston

Cohen,W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective of learning and innovation. *Administrative Science Quarterly* 35, 128-152.

Fagerberg, J., 2005. Innovation: a guide to the literature. In: Fagerberg, J., Mowery, D., Nelson, R. (Eds.), *Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp. 1-26.

Freddi, D., 2009. The integration of old and new technological paradigms in low- and medium-tech sectors: The case of mechatronics. *Research Policy* 38(2009) 548-558

Freeman, C., Louca, F., 2001. *As Time Goes By: From the Industrial Revolutions to the Information Revolution*, Oxford: Oxford University press

Freeman, C., Perez, C.,1988. "Structural Crises of Adjustment: Business Cycles and Investment Behavior." In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds), *Technical Change and Economic Theory*, London: Pinter, 36-66

Ghosal, V., Nair-Reichert, U., 2009. Investments in modernization, innovation and gains in productivity: Evidence from firms in the global paper industry. *Research Policy* 38(2009) 536-547

Gardner Publication, 2007. 2007 World machine tool output and consumption survey, http://www.gardnerweb.com/consump/survey.html.

Grant, R.M., 1996. Toward a knowledge-based theory of the firm. *Strategic Management Journal* 17, 109-122.

Grimpe, C., Sofka, W., 2009. Search patterns and absorptive capacity: Low- and high-technology sectors in European countries. *Research Policy* 38 (2009) 495-506

Heidenreich, M. 2009. Innovation patterns and location of European low- and medium-technology industries. *Research Policy* 38 (2009) 483-494

Helpman, E. (ed.), 1998. *General Purpose Technologies and Economic Growth*, Cambridge, Mass: MIT Press

Katila, R., Ahuja, G., 2002. Something old, something new: a longitudinal study of search behavior and new product introduction. *Academy of Management Journal* 45 (6), 1183-1194

Kodama, F., 1992. Technology fusion and the new R&D. *Harvard Business Review* 70 (4), 70-78.

Laursen, K., Salter, A., 2006. Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal* 27, 131-150.

Lichtenthaler, U., 2009. The role of corporate technology strategy and patent portfolios in low-, medium- and high-technology firms. *Research Policy* 38 (2009) 559-569

Liu, R.-J., Brookfield, J., 2000. Stars, rings and tiers: organizational networks and their dynamics in Taiwan's MT industry. *Long Range Planning* 33 (3), 322-348

Lundvall, B.-A., 1988. Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: Dosi, G., Freeman, C., Nelson, R.,Silverberg, G., Soete, L. (Eds.), *Technical Change and Economic Theory*. Pinter Publishers, New York, pp. 347-369.

Lundvall, B.,-A, Johnson, B., 1994. The learning economy. *Journal of Industrial Studies* 1(2), 23-41.

Mendonca, S., 2009. Brave old world: Accounting for 'high-tech' knowledge in 'low-tech' industries. *Research Policy* 38 (2009) 470-482

Niosi, J., 2003. Alliances are not enough explaining rapid growth in biotechnology firms. *Research policy* 32 (2003) 737-750

OECD, 1994. *Science and Technology Policy: Review and Outlook*. OECD, Paris.

OECD, 2003. *Science, Technology and Industry Scoreboard 2003 – Towards a Knowledge-based economy*. OECD, Paris.

Pavitt, K., 1984. Sectoral patterns of technical change: towards a taxonomy and a theory. *Research Policy* 13, 343-373

Robertson, P.L., Patel, P.R., 2007. New wine in old bottles: technological diffusion in developed economies. *Research Policy* 36 (5), 708-721.

Robertson, P., Smith, K., Von Tunzelmann, N. (2009) Innovation in low- and medium-technology industries, Research Policy, Vol. 38, pp. 441-446

Santamaria, L., Nieto, M., Barge-Gil, A., 2009. Beyond formal R&D: Taking advantage of other sources of innovation in low- and medium-technology industries. *Research Policy* 38 (2009) 507-517

Saxenian, A. 1994. *Regional advantage: Culture and Competition in Silicon Valley and Route 128*. Harvard University Press .Cambridge. MA.

Tsai, K., Wang, J., 2009. External technology sourcing and innovation performance in LMT sectors: An analysis based on the Taiwanese Technological Innovation Survey. *Research Policy* 38 (2009) 518-525

Viardot, E., 2004. *Successful marketing strategy for High-Tech firms*, 3rd Ed. Artech House, Inc.

Von Tunzelmann, N., Acha, V., 2005. Innovation in “low-tech” industries. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp. 408-432

Zahra, S.A., Keil, T., Maula, M., 2005. New ventures’ inward licensing: examining the moderating role of firm’s competitive environment. *Journal of Business Venturing* 11, 189-219.

Chapitre 4

HOW DO HIGH, MEDIUM AND LOW TECH FIRMS INNOVATE:

A COMPARATIVE APPROACH

Ziad Rotaba, Catherine Beaudry

Submitted to: International Journal of Innovation and Technology Management

4.1 Abstract

In the past decade, innovation literature has mainly targeted high-tech (HT) sectors due to their higher returns on investment and important role in building new societies and economies. While the high-tech sector is still of a leading importance, whether medium and low tech (LMT) sectors should be equivalently considered when analyzing long term economic growth, in both leading and catching-up economies, is a fundamental question. This paper is our second milestone comparatively analyzing HT and LMT sectors from an innovation perspective, while using a National System of Innovation (NSI) approach. The general aim of this paper is to find the main principles that govern the difference between the two industrial segments (HT and LMT) while controlling for supranational boundaries. In order to measure the effect of NSI, countries are divided into two groups: leading and catching-up economies. Our results suggest that, with respect to HT, leading economies could be considered the innovator, while catching-up economies are the imitators. Furthermore, HT in leading economies relies on product modularity to outsource various components probably to firms in catching-up economies. Catching-ups are putting greater emphasis on universities to produce knowledge. In addition, firms in catching-up economies benefit from high accessibility to funds in order to grow various industrial sectors, specially the LMT. The role of institutions and governments with respect to regulatory policies, intellectual property protections are of high importance for firms in catching-up economies, especially in LMT. As a result of those important steps, the various agents in catching up economies have achieved sustainable growth, notably in the LMT. In contrast, the same growth is witnessed for the HT with respect to firms in leading economies. Our results suggest that catching-up countries are strategizing for this sectoral evolution, renewal and transformation process for both sectors, but with a stronger emphasis on LMT.

Keywords: *Knowledge, systems of innovation, catching-up, low and medium technology, high technology*

4.2 Introduction

Recent history witnessed two major wars that shaped the world, the World War I and II. Prior to the two wars and in the 18^{th} century, the United Kingdom led the industrial revolution and started generating various advancements in different industrial sectors such as manufacturing, mining, transportation, and others. The products of such technological innovations marked the birth of a new world, a world that was dominated by a radically new industrial and technological innovation setup that we still live up to. Whether innovation brings war, or war brings innovation is a complex question, which is out of the scope of this paper. However, it remains unquestionable that leading nations from a technological innovation perspective enjoy wealthier economies and healthier sustainable growth.

Therefore it is interesting to develop an understanding of the differences between the leading and catching up economies, and how after the World War II, the two groups of nations dealt with technological innovations. In addition to the national segmentation, and due to the notion of convergence, it is imperative to understand how the same factors that shaped the supranational system of innovation also shaped, and were shaped by, the various sectors. It is important to highlight that after the World War II, the US dedicated a special attention to innovation in defence, safety and health (Bruland & Mowery, 2005). This extra attention led to the development of the High Tech (HT) sector, which attracted a great deal of investment from the various leading countries following in the foot steps of the US. As a result, other traditional Low and Medium Tech (LMT) sectors lost their importance to a great extent.

Recent studies (Von Tunzelmann, N. & Acha, V., 2005, Robertson et al., 2009, Santamaria et al., 2009) have demonstrated the increasing importance of LMT in innovation studies, a sector that has long been neglected in favour of the highly rewarding HT sector. The LMT industry, classically thought of as mature and slow, has started to shift from a cost based strategy towards a differentiation strategy. Furthermore, while HT and LMT dominated the developing as well as the developed countries almost equivalently, some LMT activities is witnessed to be shifting towards newly industrialized countries (Robertson et al., 2009). The renewal and transformation of any industrial sector is therefore inevitable.

This study among a series of a recently published work aims to highlight the importance of LMT, compared to HT, while adding another comparative dimension: the leading versus the catching up economies. Controlling for supranational systems will enable us to understand the context of innovation and whether it differs between the two groups or not. For instance, it is found that due to globalization, firms aiming to satisfy international customers needed to properly analyze the complex global taste while keeping safety and healthy regulation into perspective. It is further found that developed countries that enjoyed active HT, had other sectors industrially active as well Mendonca (2009).

Therefore the main topic that concerns this paper is the relationship between leading, and catching up economies, with respect to HT and LMT industries, from an innovation perspective. This is achieved by analyzing more than 500 firms distributed in the two types of economies (leading and catching up), in both the HT and LMT sectors. A system of innovation (SI) approach is used including the various agents that represent the core of national systems of innovation (NSI) and sectoral systems of innovation (SSI). Using t-tests for the comparison of means between the four groups highlighted (in Table 4.1) will enable us uncover the differences between different systems of innovation.

Our results suggest a renewal and transformation in the HT and LMT is taking place. This renewal process is not in isolation of the national system of innovation. While leading economies are primarily focused on HT, catching-up economies are more diversified, however put more focus on LMT. The paper will follow with the theoretical framework, methodology, results, analysis and finally conclusion.

Table 4. 1 SSI & NSI comparison map

HT (Leading vs. Catching up) (Group 1)	**LMT** (Leading vs. Catching up) (Group 2)
Leading (HT vs. LMT) (Group 3)	**Catching up** (HT vs. LMT) (Group 4)

4.3 Theoretical Framework

The theoretical framework will explore two dimensions. The first dimension presents systems of innovation that include both sectoral systems of innovation (SSI), national systems of innovation (NSI), and the theoretical framework based on the two systemic approaches. The second presents the literature of catching-up and leading economies from an innovation perspective.

4.3.1 Systems of innovation

This research work follows a 'systems of innovation' (SI) approach. This systematic approach for viewing innovation stems from to the necessity of incorporating innovation within its surrounding environment which constitutes the determinants of the innovation process (Edquist, 2005). This environment consists of the various important aspects that breed innovation, generally including organizational, institutional, political, social and economic factors. Consequently, when studying innovation from an SI perspective, these various factors ought to be considered, in order to properly understand the innovation phenomena. This systematic view, does not consider the mentioned entities in isolation, but in an interaction framework. For instance organizations could be other firms (like suppliers, competitors, customers, etc.) or non firm entities such as universities and governmental institutes (Edquist, 2005).

Systems of innovation can be national, sectoral and regional (Edquist, 1997). *First*, the National System of Innovation coined by Freeman (1987) can be defined as "The network of institutions in the public and private sectors whose activities and interactions initiate, import and diffuse new technologies" (Edquist, 2005). Following Freeman, Nelson (1993) and Lundvall (1992) published two books on NSI:, Lundvall (1992) places interaction between the various agents, and learning centrally in the analysis, while Nelson (1993) focuses solely on a nation's research and development systems, as a catalyst of the innovation process. Both Lundvall and Nelson define NSI by determining the factors influencing innovation (Edquist, 2005). *Second*, the sectoral approach developed by Breschi and Malerba (1997) puts more emphasis on production, and utilization of technologies by the various sectors. *Third*, regional systems of innovation were first introduced by Cooke et al. (1997), concentrate on the local interactions between organizations (Edquist, 2005).

Figure 4.1 presents our sectoral and national systems theoretical framework. This national system will bypass geographical boundaries to include the two groups studied, the leading and catching-up economies. According to Malerba (2004), sectoral innovation is affected by three main entities: knowledge and technologies, actors and networks, and institutions. First, *knowledge and technologies* represent the sectoral knowledge base, technologies and inputs, and are responsible of the sector's boundaries. This is why its box leads to dynamics and growth patterns that influence the sector's evolution and transformation. Second, *actors and networks* simply represent the various organizational entities involved in the innovation process such as firms and financial organizations, or non-organizational entities such as universities. The customers that can take various forms of organizational structures are the demand creators, and are a fundamental part of the sectoral system of innovation. Using a knowledge-based view of the innovation process, the different entities are all interconnected by arrows. Third, *institutions* are basically the bodies responsible of norms and routines, such as public funding institutions, regulation and standards institutes. Such institutions have both sectoral and national roles.

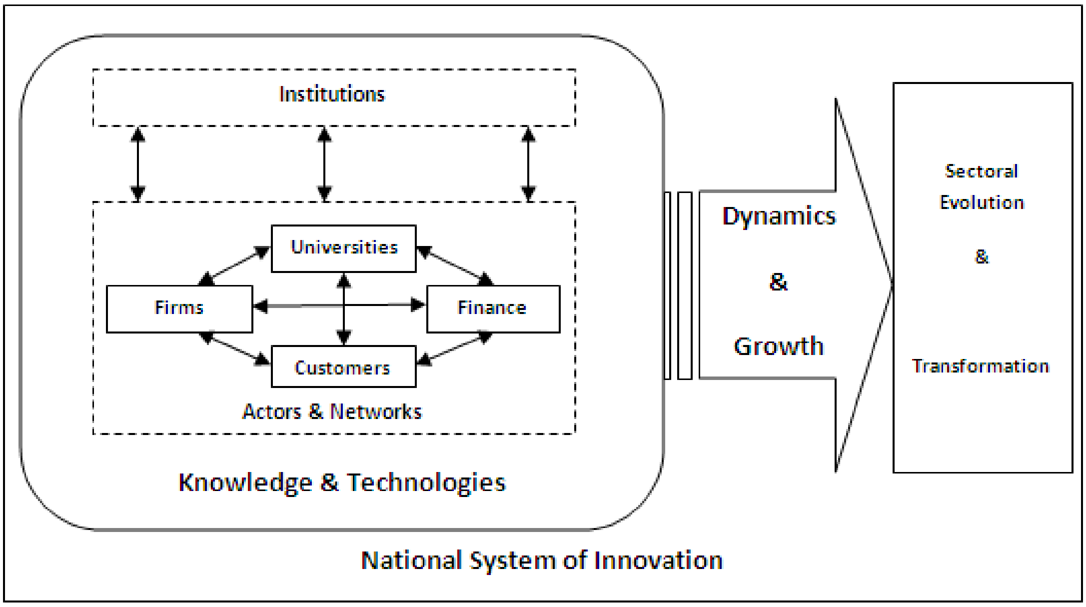


Figure 4. 1 SSI and NSI Theoretical Framework

The representation of our theoretical framework not only follows Malerba's (2004) view of an SSI, it also takes into consideration Freeman's (1987) structure representing the network of institutions, and their interactions. These interactions will generate the learning process, a phenomena that is heavily supported by Lundvall (1992). Due to the dynamic nature of the interactions and of learning, sectors go through various dynamic and growth patterns that result into the evolution of the sector and its transformation. Each block in Figure 4.1 will be represented in the questionnaire used for our research, and described below.

In order to process to our analysis, two main questions remain to be answered:

1. What is the main difference between LMT and HT according to each of the variables of our theoretical framework?
2. What is the main difference between leading and catching up economies according to each of the variables of our theoretical framework?

According to figure 4.1, the LMT and HT are addressed from sectoral/national systems of innovation. Table 4.2 illustrates our general understanding of the importance of each element based on the literature, classified into low, high and moderate. Knowledge and technologies are investigated from five angles. The first and second are addressing whether firms gain knowledge by accumulation from inside the firm (KTIn) or rather by interactions with other firms (KTOut). Furthermore, systems integration (KTSys) is considered to be a way of exchanging knowledge about the various systems standards, especially between the various suppliers. The last angle considers whether knowledge is actually the production of a stable (KTStab) or more dynamic technological base. Recent literature suggest that LMT firms depend more heavily on their suppliers, and hence are more oriented towards open innovation, whilst HT firms are more oriented towards the linear model of innovation, depending mainly on their internal R&D production, while using collaboration and open innovation to develop technologies that cannot be provided from within the firm. Both sectors integrate systems; however, due to the modularity that is currently very widely used in HT, we can generally claim that the HT would be more dependent on systems integration than LMT. HT is viewed to be more of a turbulent sector that enjoys dynamic technological change, compared to LMT that is considered to be more stable, mature and less dynamic. Furthermore, the HT is the main producer of General Purpose Technologies (GPT), while the LMT is the main user of GPT (Robertson et al., 2009, Freddi, 2009) (KTGPT).

The element relating to actors and networks consists of universities, firms, customers (demand) and finance. HT is very dependent on scientific knowledge that is mainly the main production of universities (ANUniv), compared to LMT that is more dependent on practical solutions that are widely shared between customers and suppliers. This is why; universities were marked with ‘low’ with respect to LMT, while it is ‘high’ with respect to HT.

Firms’ strategy can include the following: supplier dependency (ANSupp), modularity (ANMod), war of standards (ANStd), cost\differentiation orientation (ANCost), or process\product innovation (ANInnov). While both sectors depend on suppliers, however LMT (specially the low techs) is definitely a supplier-dominated sector according to Pavitt’s (1984) taxonomy. For this reason, LMT is assigned a ‘high’ importance, while HT is assigned a ‘moderate’ importance for supplier dependency. While modularity is commonly used across the various sectors, comparatively, HT products are more modular than LMT ones. Due to this modularity, standards have a higher effect on HT than their counterparts. In addition, LMT as a mature sector is considered to be cost oriented, while HT is rather oriented towards technological differentiation. Furthermore, demand is generally more complex in HT than in LMT. With respect to financing, it is expected that HT is receiving better financing, than classic sectors.

Regarding the role of institutions, regulations (IReg) are an important aspect when it comes to the diffusion of HT technologies. This factor is indeed crucial for LMT especially with the increasing role of globalization, and the rise of various health and security international policies. As HT is to be considered a principal component of the knowledge economy, knowledge in that sector is a product that should be protected. Hence, for HT, the role of intellectual property protection (IIP) is generally more central than for LMT. Governmental funding and support (IGov) is still generally directed to HT due to its important role in our current economies. In contrast to HT, LMT does not enjoy much of that support due to its slow growth.

Dynamics and growth are represented by various factors that include growth (DGGrowth), pace of change (DGPace), firm entry (DGEntry), incumbent firms challenge (DGIchal), rival challenge (DGRchal) and battles of cost (DGCost). As HT is more dynamic and provides more growth than LMT, all factors are marked with ‘high’ in favour of HT, with the exception of two factors. Incumbent firms challenges is not low in LMT, where in fact incumbent firms enjoy early mover advantages that are hard to penetrate by rival new entrants. The other factor relates to battles of cost, where generally mature sectors are more inclined to be more competitive on cost rather than younger sectors that use technological differentiation as a core competitive advantage. Finally, with respect to sectoral evolution and transformation, it is measured by four main factors: technological frontier advancement (ETTech), sectoral transformation (ETTrans), sectoral redefinition (ETRedef) and unpredictable sectoral development (ETDev). Since HT is a

Table 4. 2 HT and LMT from an SSI \ NSI view

SSI & NSI Basic Components	Elements		Variable	LMT	HT
Knowledge and Technologies	Accumulation Inside Firms		KTIn	Low	High
	Firms Interactions		KTOut	High	Low
	Systems Integration		KTSys	Moderate	High
	Technological Stability		KTStab	High	Low
	General Purpose Technologies (GPT)		KTGPT	Low (Using)	High (Producing)
Actors and Networks	Universities		ANUniv	Low	High
	Firms Strategy	Supplier Dependency	ANSupp	High	Moderate
		Modularity	ANMod	Low	High
		War of Standards	ANStd	Low	High
		Cost Orientation	ANCost	High	Moderate
		Process\Product Innovation	ANInnov	Process	Product
	Demand	Customers & Complexity of Need	ANNeed	Low	High
	Finance		ANFin	Low	High
Institutions	Regulatory		IReg	Moderate	High
	Intellectual property		IIP	Low	High
	Government Funding & Support		IGov	Low	High
Dynamics and Growth	Sectoral Growth		DGGrowth	Low	High
	Dynamics	Pace of change	DGPace	Low	High
		Firm's entry	DGEntry	Low	High
		Incumbent firms challenge	DGIchal	Moderate	High
		Rival challenge	DGRchal	Low	High
		Battles of Cost	DGCost	High	Moderate
Sectoral Evolution and Transformation	Technological Frontier Advancement		ETTech	Low	High
	Sectoral Transformation		ETTrans	Moderate	High
	Sectoral Redefinition		ETRedef	Moderate	High
	Unpredictable sectoral Development		ETDev	Low	High

more dynamic and growing sector we can infer that its sectoral evolution and transformation will be higher than LMT across all factors. However, since recent literature supported the propensity of LMT transformation and redefinition, we can generally claim that the two factors could be assigned a 'moderate' mark.

4.3.2 Catching-up and leading economies

"'Catch-up' relates to the ability of a country to narrow the gap in productivity and income vis-à-vis a leader country" Fagerberg and Godinho (2005, p.514). In the nineteenth century, the United Kingdom was classified as the leader, while the United States and Germany were trying to catch-up. This process of narrowing the gap between the leader and the follower was not the result of pure imitation. Indeed it was done by bringing new ways of organizing production and distribution, in other words through innovation (Freeman and Soete 1997; Freeman and Louca 2001). These two thoughts of innovation versus imitation process have been examnied by Van Schaik and Van de Klundert (2010) when analyzing 21 OECD economies from 1960 to 2005. They found that two sub-period of technological change is identifiable. The first is based on imitation; the second is predominantly based on innovation.

In 2007, the society of manufacturing engineering (Sme, 2007) highlighted that the US is still leading the entrepreneurial performance; however, other nations are catching up. It is estimated that by 2020, this catching up process will be at its peak. This will be due to multiple reasons the most important of which is that middle class consumer demand will emerge from non-industrialized countries. Furthermore, China is becoming the most attractive destination for off-shore R&D activities. When analyzing the compact disc player in China, Xie and Zedtwitz (2010) stated that innovation is mainly pulled by local markets rather than technology push.

According to Fagerberg and Godinho (2005), the catching up literature includes three important views: the first is that of Thorstein Veblen and Alexander Gerchenkron who analyze the catching up of Germany to the UK and the role of institutions to realize the process; the second is the literature of Asian (including Taiwan, South Korea and others) catching-up to the Japanese way; finally the third relates to the role of technology and innovation resulting in long run economic growth.

European history is central to the understanding of the catching-up phenomena. Veblen (1915) was the first to realize that "recent technological changes altered the conditions for industrialization in latecomer economies" (Fagerberg and Godinho, 2005, p.516). At the beginning of the industrial revolution, knowledge was tacitly embedded in skilled workers, and hence knowledge transfer was the result of these workers' mobility. However, with the recent advances in the codification of knowledge, latecomers can actually take the full benefit from the technology without contributing to any cost of its development. Veblen predicted this catching-up phenomena for other European countries such as France, Russia, Italy and Japan.

Alexander Gerchenkron (1962) did not share the same opinion as Veblen (1915). Gerchenkron argued that Veblen's view of the catching-up phenomena was based on the case of UK and Germany. This form of industrialization that Britain has witnessed at that time was actually small scale and fitted Veblen's view that did not include the important role of institutions. Therefore, according to Gerchenkron, to succeed, catching-ups should develop separate institutional instruments that are uniquely distinguishable from that of leading economies. Consequently, Gerchenkron attributed the successful catch-up to the role of banks, governments or private organizations in the industrialization process (Fagerberg and Godinho, 2005).

Literature explaining the catching-up phenomena of the Asian countries post WWII followed either Veblen or Gerchenkron views. However most researchers like Shin (1996) and Wade (1990) would agree that the Asian catch-up strategies were much aligned to Gerchenkron's views. Gerchenkron's view on the role of banks together with governmental support to promote catching-up is evident in post WWII Japan (Fagerberg and Godinho, 2005). The role of banks and governmental support grew, compared to the private investors and family ownership that prevailed before the war. With time, the role of the state decreased, and the Japanese banking system was solid enough to sustain the industrial catching-up. Furthermore, the Japanese case highlighted the role of process innovation in the catching-up process. As such, the Japanese case was a leading example for other catching up economies in Asia such as South Korea and Taiwan (Fagerberg and Godinho, 2005).

On the macro view, according to Fagerberg and Godinho (2005, p. 524), Abramovitz (1986 & 1994) explains the discrepancies between countries performances by "congruence and social capability". The first concept is basically how national systems are different from, or similar to, each other in terms of various economic characteristics such as factor supply and market size. The second concept includes various factors such as the education level and the levels of investment in R&D as well as the role of the financial system to mobilize resources (Fagerberg and Godinho, 2005).

4.4 Data and Methodology

4.4.1 Data

Data is the result of a survey questionnaire[2] sent in the scope of project MINE to more than 900 firms. Firms with substantial missing data for our analysis were eliminated and only 545 firms were considered in our analysis. The study uses cross-sectional data that should provide excellent insights into a wide range of descriptive issues (Chandler, 1962). The answers are represented by a Likert scale from 1 to 7, where 'one' denotes the respondent disagreement of the statement and at the other end, 'seven' implies a 'totally agree' response. The study is thus based on firm level data. All firms are sorted according to their primary activity, and are also confirmed by their North American Industry Classification System (NAICS). Leading economies in our sample are represented by Canada, France, the UK and the USA. Catching-up economies include China, Taiwan, South Korea, and Peru. These 7 economies shared 73% of the critical mass of their overall sample in their own group.

4.4.2 Methodology

This paper tests for the equality of means between HT and LMT, across industrialized and newly industrialized economies. Firms sample size representing HT leading countries (Group 1), HT catching-up economies (Group 2), LMT leading countries (Group 3), and LMT catching-up

---

[2] We are thankful to Prof. Roger Miller for providing us with the survey questionnaire, and the data in the scope of project MINE used in this study. Only selected variables from the questionnaire were selected and re-adapted to our problematic and the theoretical framework accordingly.

economies (Group 4) are 111, 88, 195, 151 firms respectively. The t-test for equality of means is carried out with groups 1 vs. 2, 3 vs. 4, 1 vs. 3 and finally 2 vs. 4.

In order to use the t-test for different sample sizes, data is tested for normality for the various sample sizes. This first verification is carried out by checking the kurtosis and skewness of the data. The values of kurtosis and skewness are found to be around '0' and are in the interval [-1, +1]. It is concluded that data is normally distributed. Levene's test is carried out to verify the equality of variances, between the various samples. In the Levene test, if $p \leq 0.05$ then the t-test for unequal variances and unequal sample size is used. If $p > 0.05$ then the t-test for equal variances and unequal sample size is used. Each table in the next section presents the results of the t-tests for equality of the means between the various groups from 1 to 4 (In table 4.3). The t-test results follow a 2 tailed representation. Therefore, the result of the 2 tailed representations is divided by two to transform the two-tailed scale into a one-tailed scale. In results tables, non significant p values are labelled (NS) and are shadowed.

4.5 Results

4.5.1 Knowledge and Technologies

Accumulation of knowledge inside firms across the four groups is comparatively non significant (KTIn). However, with all averages above 5 on the scale, it shows that internal R&D development is crucial to firms' survival, regardless its economical or sectoral boundaries. This support's other researchers' findings like Tsai and Wang (2009) demonstrating that even firms with a higher dependability on external R&D, perform better when improving their internal R&D absorptive capacity. Results show that knowledge generation through interaction (KTOut) in LMT is the most significant across all groups, in favour of the catching economies. However these interactions are significant in leading economies with respect to HT. When comparing groups 1-2, and 2-4 results are non significant. The most significant result, when it comes to systems integration (KTSys) and the knowledge generated during such a process is the HT in leading economies, when compared to the LMT in the same economies. HT of leading economies views systems integration as a more centric process than the same sector in catching up economies. However, if the two economies are compared, LMT in catching up economies relies more on system integration to generate knowledge.

LMT in both economies rely more on a stable technological base (KTStab). This is in contrast to HT that enjoys a more dynamic technological environment. Interestingly, Catching-up economies, perceive knowledge generation to be more dependent on a stable technological base, compared to leading ones. This could hint that while the leaders are the innovators in both sectors, the catching-ups are the imitators. General Purpose Technologies (GPT) is the product of HT. However, if comparing catching-up and leaders with respect to GPT (KGpt), results are non-significant, suggesting a kind of closeness in the way knowledge is used to produce GPT in both economies.

4.5.2 Actors and Networks

When comparing HT or LMT in catching up economies, non-significant results occupy the majority of the innovation context (see 2 vs. 4 inTable 4.3). This probably suggests that the HT and LMT sectors are similarly viewed by catching-up countries. In both types of economies, HT is more aligned with universities (ANUniv1 & ANUniv2) to produce knowledge than LMT. However, when the two economies are compared controlling for one sector, catching-up economies are seen to be putting extra focus on knowledge produced from universities. This result supports the findings of Mazzoleni (2008) who discovered that for a successful catching up process, academic institutions have to contribute to the development of firm level capabilities. This kind of close interaction between the academic and industrial sectors, together with the government has been emphasized by Tu and Yang (2008) to promote Taiwan's Science and Technology (S&T) contribution to the catching-up process.

Suppliers play a key role in HT located in leading countries, compared to LMT in their own economies (the leading one) (ANSupp). This suggests that while the core products architectures are still produced in leading economies, the dependency on external suppliers probably increased particularly with the general trend of product modularity. This is supported by Xie and Zedtwitz

(2010) who found that on the supply side, suppliers from leading economies play a key role for firms in China to produce world-first products and innovations. For instance, in both types of economies, HT still is more dependent on product modularity (ANMod). However, leading economies are probably incorporating modularity in their firm's innovation strategies better than catching up economies. A good explanation is that firms in leading economies produce modular products, and then outsource components to catching up economies. This downstream integration capability is essential for catching-up economies to succeed (Xie & Zedtwitz, 2010). Furthermore, this intra-industry trade has increased products quality, and enhanced the catching up process for Eastern European countries and their EU partner (Cavallaro and Mulino, 2008).

This could be one of the reasons why HT in leading economies became more suppliers dependent. For that reason our results show that the standards war (ANStd) is better mastered by leading economies especially in the HT sector.

Cost is represented by two variables, one related to cost as a constraint facing firms (ANCost), the second is related to reducing cost by increasing the scale of operations (ANCostScl). Generally more than 50 percent of the results are NS for all comparison. For instance, with respect to cost as a constraint (ANCost), the only significant comparison is that comparing LMT and HT in leading economies (1vs3) in favour of the LMT. This demonstrates the most of the firms in the two economies generally perceive cost as a major determinant for their strategic directive, with a higher emphasis on LMT in leading economies. Furthermore, scale contributing to cost reduction (ANCostScl) is the most significant when comparing LMT in both economies, in favour of Catching ups. This hints that catching ups are probably using higher scale production to minimize cost in LMT, probably due to their relatively lower cost of labour and scale intensive operations. This mix between integration capabilities, with competitive pricing has been stressed by (Xie & Zedtwitz, 2010).

Investigating the role of product process innovation on the firms' level (ANInnov), Catching-up economies rely more on process innovation, especially in LMT that seems to be a core sector. This shows in the comparison of 3vs.4 and 2 vs. 4. This is consistent with our general understanding that reinforces the high value of LMT to the catching up process. In other words, since LMT is generally considered to be process innovation driven, firms in countries encouraging LMT should be also highly focused on process innovation. That finding is consistent with those of Merikull (2010), studying eastern European countries. Based on the Estonian community innovation survey (CIS), it was found that innovation affects positively employment growth in the Estonian LMT sector, where the stronger effect was caused by process innovation. This highlights the importance of process innovation to the catching process.

HT is generally facing a more complex demand (ANComp) compared to LMT. The complexity of demand in leading economies surpasses that of the catching up economies. This probably explains that leading economies, while focusing on local markets definitely try to penetrate foreign markets. This is evident from the behaviour of American multinational enterprises scattered all over the globe that aim to satisfy demand from various global users. The rise of product modularity certainly enables firms to better customize their products to fit a variety of customer needs and demands. In addition to complexity, experienced customers (ANComp) about product's operation hold the highest significance for the LMT sector when the two economies are compared. This demonstrates the importance of clients to firms in the LMT specially in catching up economies that seems to highly value the role of interaction with clients to better customize demand.

What is even more interesting is that innovative start-ups, in catching up economies, enjoy a higher level of accessibility of funds to grow their businesses (ANFin). This result is consistent in both the HT and LMT. However, the LMT holds a very high significance. This result supports the findings of Hsieh and Lofgren (2009), highlighting the importance of funds accessibility for the catching up process in Korea, Singapore and Taiwan. Fund could take the form of public investments and grants or Foreign Direct Investment (FDI).

4.5.3 Institutions

Catching-up economies are more concerned with regulatory approvals (IReg) in the LMT sector. This suggests that catching up economies that are very dependent on exports take regulations seriously before their product commercialization phase as a part of their institutional setup. Furthermore, in both sectors, catching-up countries seem to be taking important measures to avoid any imitation strategy (IRegIm) of their own innovations. This is even more apparent from the fact that intellectual property protection (IIP) is very significantly in favour of catching ups versus leading economies, and in the two sectors. This effectiveness in utilizing the intellectual property system indicates the importance of efficiently capturing value from innovations for firms in catching up economies.

Governmental support (IGov) is witnessed in the high tech industry in both economies. While this support is clear in the case of leading economies, it is important to further analyze it from the catching-up economies angle. If we take the biopharmaceutical sector in South Korea, Singapore and Taiwan, Hsieh and Lofrgen (2009) relate the catching up process in that sector to two important government related factors. First, is the public investment in R&D. Second, is the role of catching-up governments to promote high tech industries by promoting public investment, establishing R&D tax credits. According to Hsieh and Lorfrgen (2009) this governmental role is indispensable for the catching up process especially in the high tech industries. It is also important to mention that catching-up governments are mixing the sources of funds between FDIs and local governmental funds. This mix in the sources of funds has been proven to be a success for the catching up process (Bellone, 2008).

From a comparative approach the results are insignificant. Still leading economies and catching up economies are giving extra attention to that sector if compared to the LMT one. However some more focus is given to LMT in catching economies if compared to the leading economies.

4.5.4 Dynamics and Growth

Catching-up economies, with respect to both sectors, are witnessing a remarkable growth compared to that of leading economies (DGGrowth). This growth reaches the highest significance for LMT, but HT is still over shadowing LMT in leading economies. The dynamics of this growth are further supported by the several variables representing the pace of change (DGPace), firm entry (DGEntry) and rival challenges (DGRChal), as well as battles of cost

(DGCost). For instance, the pace of technological change (DGPace), induced by entry (DGEntry) in catching-up economies is very clear and with a very high significance in the LMT sector. This result demonstrates that catching-up economies are already following the latest recommendations of the OECD economic survey of 2010. The recommendation of OECD (2010) aims to reduce the cartels effect in order to strengthen competition and enhance the catching-up process. When comparing HT and LMT in catching up economies, we can find that the HT industry is characterized with a higher entry rate. This hints towards the flexibility of HT firms in catching up economies: a phenomena that supports the findings of Li and Kozhikode (2008) when analyzing the Chinese mobile phone industry.

This rise in the role of entry (DGEntry) is opposed by a somehow relaxed role of incumbent firms (DGIChal) that are only able to control competition in their own economy. Catching-up economies are pushing the HT renewal and transformation process by maintaining a cost competitive (DGCost) advantage, as a core strategy for their firms.

SSI & NSI Basic components	Elements		Variables	Group 1 HL	Group 2 HC	Group 3 LML	Group 4 LMC	1 vs. 2 P/2 [1-2]	3 vs. 4 P/2 [3-4]	1 vs. 3 P/2 [1-3]	2 vs. 4 P/2 [2-4]
Knowledge & Technologies	Accumulation Inside Firms		KTIn	5.48	5.38	5.32	5.26	0.2735 NS	0.3360 NS	0.1420 NS	0.2605 NS
	Firms Interactions		KTOut	4.55	4.76	4.05	4.59	0.1445 NS	0.0005 ****	0.0030 ***	0.1730 NS
	Systems Integration		KTSys	5.63	5.39	4.56	5.00	0.0995 **	0.0035 ***	0.0000 ****	0.0150 **
	Technological Stability		KTStab1	4.86	4.80	4.38	4.49	0.3800 NS	0.2505 NS	0.0035 ***	0.0570 **
			KTStab2	3.99	4.58	4.51	5.03	0.0035 ***	0.0005 ****	0.0045 ***	0.0065 ***
	General Purpose Technologies (GPT) Production		KGpt	5.12	5.21	4.60	4.89	0.3510 NS	0.0445 **	0.0055 ***	0.0510 *
Actors and Networks	Universities		ANUniv1	4.80	5.22	4.05	4.66	0.0210 ***	0.0000 ****	0.0000 ****	0.0015 ***
			ANUniv2	4.52	4.93	3.51	4.74	0.0295 ***	0.0000 ****	0.0000 ****	0.1620 NS
	Firms Strategy	Supplier Dependency	ANSupp	5.83	5.34	5.22	5.23	0.0035 ***	0.4710 NS	0.0000 ****	0.2765 NS
		Modularity	ANMod	6.25	5.41	5.51	5.20	0.0000 ****	0.0340 **	0.0000 ****	0.1655 NS
		War of Standards	ANStd	5.99	4.76	4.93	4.82	0.0000 ****	0.2630 NS	0.0000 ****	0.3845 NS
		Cost Orientation	ANCostScl	4.89	5.26	4.79	5.48	0.0345 **	0.0000 ****	0.2955 NS	0.1210 NS
			ANCost	4.75	4.89	5.27	5.10	0.2695 NS	0.1360 NS	0.0025 ***	0.1350 NS
		Process\Product Innovation	ANInnov	4.22	4.20	4.33	4.71	0.4555 NS	0.0100 **	0.2840 NS	0.0040 **
	Demand	Customers & Complexity of Need	ANExp	5.06	5.34	4.65	5.40	0.0850 **	0.0000 ****	0.0130 **	0.3505 NS
			ANComp	5.92	5.53	5.26	5.06	0.0150 ***	0.1175 NS	0.0000 ****	0.0040 ***
	Finance		ANFin	3.36	3.67	2.91	3.48	0.0820 *	0.0000 ****	0.0110 **	0.1670 NS
Institutions	Regulatory		IReg	4.47	4.58	4.15	4.77	0.3465 NS	0.0025 ***	0.0970 *	0.2250 NS
			IRegIm	3.48	4.32	3.34	4.34	0.0005 ****	0.0000 ****	0.2520 NS	0.4660 NS
	Intellectual property		IIP	4.43	5.28	3.77	4.84	0.0000 ****	0.0000 ****	0.0005 ****	0.0115 **
	Government Funding & Support		IGov	3.86	3.71	3.06	3.30	0.2490 NS	0.0875 *	0.0000 ****	0.0345 **
Dynamics and Growth	Growth		DGGrowth	4.05	4.59	3.08	4.45	0.0070 ***	0.0000 ****	0.0000 ****	0.2390 NS
			DGNiche	4.79	4.58	3.91	4.46	0.1695 NS	0.0005 ****	0.0000 ****	0.2675 NS
	Dynamics	Pace of change	DGPace	4.82	5.26	3.36	4.34	0.0235 **	0.0000 ****	0.0000 ****	0.0000 ****
		Firm's entry	DGEntry	4.19	4.60	3.05	3.91	0.0390 **	0.0000 ****	0.0000 ****	0.0005 ****
		Incumbent firms challenge	DGIchal	5.27	5.18	4.87	4.93	0.3110 NS	0.3565 NS	0.0050 ***	0.0995 *
		Rival challenge	DGRchal	4.58	5.00	4.24	4.97	0.0120 **	0.0000 ****	0.0170 **	0.4450 NS
		Battles of Cost	DGCost	4.33	4.93	4.52	4.67	0.0040 ***	0.2065 NS	0.1780 NS	0.1095 NS
Sectoral Evolution and Transformation	Technological Frontier Advancement		ETTech	4.97	5.24	3.33	4.35	0.0960 *	0.0000 ****	0.0000 ****	0.0000 ****
	Sectoral Transformations		ETTrans	4.76	4.95	4.49	4.87	0.1575 NS	0.0100 **	0.0745 *	0.3145 NS
	Sectoral Redefinitions		ETRedef	4.95	4.83	4.10	4.28	0.2890 NS	0.1500 NS	0.0000 ****	0.0030 ***
	Unpredictable sectoral Development		ETDev	4.08	4.84	3.63	4.45	0.0000 ****	0.0000 ****	0.0095 ***	0.0200 **

Notes: ****, ***, **, * represent significance at the 0,1%, 1%, 5% and 10% levels respectively.
Group 1 = HT Leading countries (N=111)
Group 2 = HT Catching up countries (N=88)
Group 3 = LMT Leading countries (N=195)
Group 4 = LMT Catching up countries (N =151)

Table 4. 3 Mean comparison analysis between the 4 groups

4.5.5 Sectoral Evolution and Transformation

Finally, the fifth set of rows of **Error! Reference source not found.** addresses the sectoral evolution and transformation. HT, compared to LMT, in both catching up and leading economies is witnessing a higher advancement in its technological frontier (ETTech), sectoral transformation (ETTrans) and redefinitions (ETRedef). Furthermore, it is perceived to be dominated by unpredictable sectoral development (ETDev). However, if we control for sector, catching-up economies seem to be more strategizing for this sectoral evolution and transformation process. This suggests that catching-up economies are a prime player into the renewal and transformation of the both sectors, with a stronger emphasis on the LMT.

4.6 Analysis and Discussion

4.6.1 Knowledge and Technologies

Internal R&D development is crucial to firms' survival, regardless its economical or sectoral boundaries. For catching-ups, this result is in line with Fan's (2006) (Wei et al., 2005) recommendation when studying the Chinese Telecommunication Equipment Industry (TEI). The author asserts that for a successful catch-up, in the TEI should focus on in house R&D development together with their focus on external alliances.

Also this result supports the findings of Fagerberg and Godinho (2005) who stated that catching-ups such as South Korea and Taiwan invest more than 1.5% of their GDP in R&D. This demonstrates the race with leading countries like the US, France and the UK.

Knowledge generation through interaction in LMT is the most significant factor in favour of the catching economies. In general, previous studies showed that this kind of interaction is central to successful LMT, due to its cost efficiency, and the high quality of knowledge produced due to interactions between the various actors of the sectoral system, such as suppliers and clients. These interactions however are significant only in leading economies with respect to HT.

Result 1: Aside from internal R&D development, knowledge generation through firm's interactions is central to the strategic innovation context of LMT in the catching up economies.

In terms of knowledge generation through systems integration, on the one hand, HT of leading economies views systems integration as a more central process than the same sector in catching-up economies. On the other hand, LMT in catching-up economies relies more on system integration to generate knowledge

Result 2: Leading economies are more efficiently using systems integration in the HT sector, while catching-up economies are utilizing system integration in the LMT sector.

LMT in both economies rely more on a stable technological base. This is in contrast to HT that enjoys a more dynamic technological environment. Interestingly, catching-up economies, perceive knowledge generation to be more dependent on a stable technological base, compared to leading ones. This could hint that while the leaders are the innovators in both sectors, the catching-ups are the imitators. General Purpose Technologies (GPT) is always the product of HT. However, if comparing catching-ups and leaders with respect to GPT, results are non-significant, suggesting a kind of closeness in the way knowledge is used to produce GPT in both economies.

Result 3: In both economies, HT relies on less stable technological base, while LMT utilizes a more stable one. However, catching-up economies are generally using a more stable technological base than leading economies.

Result 4: The leaders are innovators, while catching-ups are imitators.

4.6.2 Actors and Networks

Results suggest that in catching-up economies, both sectors are similar; none is gaining extra attention over the other. Moreover, catching-up economies are putting a higher emphasis on knowledge produced from universities to benefit both sectors. This supports the comments of Fagerberg and Godinho (2005) indicating that whilst leading economies hold a higher percentage of university enrolment, catching-ups are not far from reaching the same level.

Result 5: While catching-up economies assign a diversified attention to both the LMT and HT, leading economies are focused on HT. Additionally, realizing its importance, catching-ups economies are putting a greater emphasis on universities to produce knowledge.

It is important however to highlight that some catching up economies such as Mexico, have been found to be less dependent on direct collaboration with universities, rather on university industry collaboration as a source of technological knowledge (Norma, 2005)

Suppliers play a key role in HT located in leading economies, compared to LMT in their own economy (the leading one). This suggests that while the core products architectures are still produced in leading economies, probably the dependency on external suppliers increased specially with the general trend of product modularity. However, it is essential to mention that recent research has found that the Chinese automobile industry is recently shifting from the integral architecture to a quasi open modular architecture (Wang, 2008). Following that strategy firms buy licenses or copies of generic parts and integrates the various components depending on the end product.

Result 6: Firms in leading economies produce modular products, and then outsource components to catching up economies.

Result 7: Catching-up economies rely more on process innovation, especially in LMT that seems to be a core sector.

The complexity of demand in leading economies surpasses that of the catching up economies. This probably explains that leading economies, while focusing on local markets definitely try to penetrate foreign markets.

Result 8: Leading economies firms face an even more complex demand that is satisfied by increasing products modularity.

What is even more interesting is that innovative start-ups, in catching up economies, enjoy a higher level of accessibility of funds to grow their business. This result is consistent in both the HT and LMT. However, the LMT holds a very high significance. This shows a focus on that sector in catching up economies. This supports the Gerschenkronian view that successful catching-ups depended more on their internal ability to enhance their institutional role to invest properly in education, innovation and R&D (Fagerberg & Godinho, 2005).

Result 9: The economic system of catching-up economies is perceived to better facilitate accessibility of funds to grow the various industrial sectors with a high significant result for LMT.

4.6.3 Institutions

The important role of institutions, supporting Gerschenkronian's view, is clear in our analysis. Catching-ups do not only focus on education, in fact the regulatory framework in which catching-ups institutions played a key role is evident. This importance is obvious in the case of HT in leading economies. More importantly, this role is paralleled by a similar role in catching ups with respect to LMT. One the one hand, leading economies protect their HT investments by developing the appropriate regulatory policies. On the other hand, catching-ups are reinforcing the role of institutions especially in the case of LMT, as a mean to catch-up. This result is logical, if the economic and technological perspectives of LMT are investigated. For instance, LMT firms in catching-ups, that generally are export with export, should give key attention to regulatory approvals through their institutions in order to protect their investments. In the same vein, since catching-ups cannot afford much knowledge dissipation, intellectual property protection is mandatory to properly utilize innovations and protect their R&D investments. This institutional setup is supported by governments especially in the case of LMT in catching-ups.

Result 10: Focused on LMT and export, catching up institutions play a key role to expand their global market share by seriously adhering to regulatory policies before the commercialization phase.

Result 11: In catching up economies, intellectual property protection institutions play a key role of efficiently capture value from innovations, and protect own production to avoid imitation.

Result 12: Governments for both economies are giving extra attention to HT. However; governments in catching-up economies are giving extra focus to LMT.

4.6.4 Dynamics and Growth

The result of the above factors resulted into dynamics and growth of the LMT sector especially in catching-ups. Leading economies are seen to be solely focused on HT, with probably a diminishing growth. Catching-ups perceive growth in both sectors with a clear growth in LMT, that leading economies seemed to be not giving much attention for the sake of HT. While it is unmistakable that HT is the main engine for growth, this statement could be losing its absoluteness with time. One explanation is that HT perhaps has climbed its S shaped curve of technological innovation, and getting to be more of a stable and less turbulent sector. In contrast, LMT that is considered the user of the HT produce now has a variety of technologies to deploy to enhance their process innovation, thus adding to differentiate their products portfolio. This suggests the renewal and transformation of such old, and slow growth perceived sector. Not only does technological differentiation, offered by the HT technologies support LMT firms, in fact this is coupled with a cost based strategy.

Result 13: In terms of growth, firms in catching-up economies perceive more growth in both sectors with a higher significance for LMT. Still their leading counterpart is more focused on HT that takes the lion's share of attention.

Result 14: The pace of technological change in catching up economies in the LMT sector is clear. In addition, firms in the catching-up economies are driving a cost based strategy in the HT sector pushing for a renewal and transformation process.

4.6.5 Sectoral Evolution and Transformation

As a result of the above dynamics and growth elements, the LMT in both economies is witnessing advancement in its technological frontier. And hence, this sectoral transformation and redefinition is evident. However, this renewal and transformation places strong emphasis on LMT in catching-ups that seems to have managed to attract that sector to its own national boundaries, and finally lead this transformation and renewal process.

Result 15: compared to LMT, in both catching up and leading economies is witnessing a higher advancement in its technological frontier, sectoral transformation and redefinitions.

Result 16: Catching-up economies are strategizing for this sectoral renewal and transformation process with a stronger emphasis on the LMT.

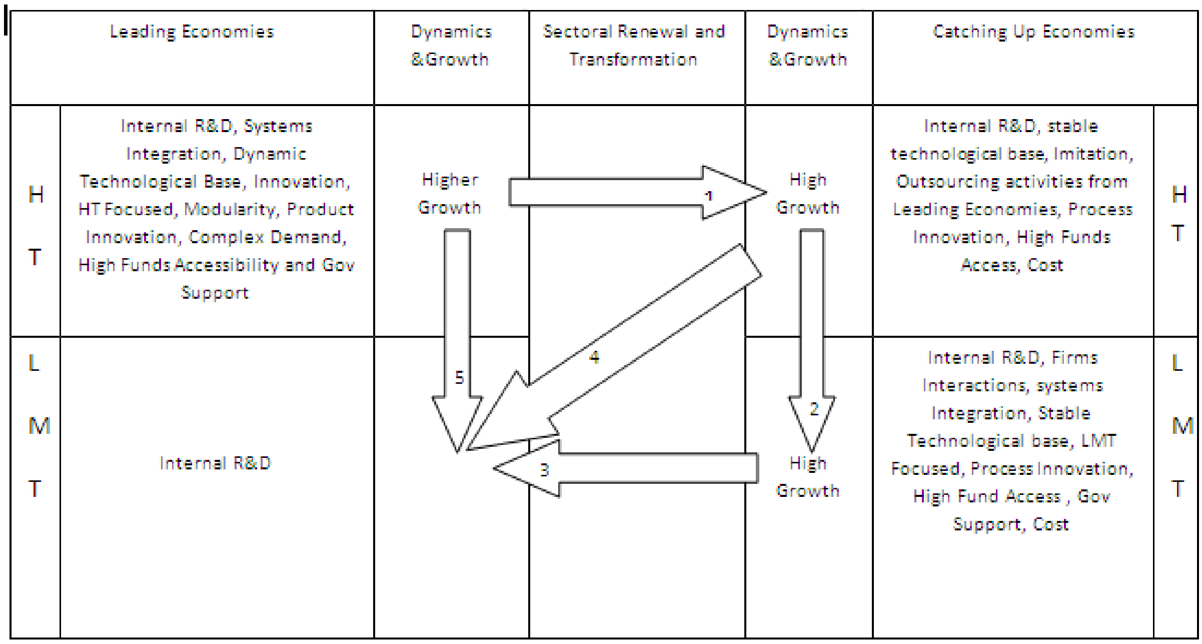


Figure 4. 2 Conclusion LMT, HT, Leading and Catching Ups

Figure 4.2 shows the various dynamics affecting each sector and each economy. Arrows represent the dynamics. Breakthrough innovations and technologies are commercialized to the HT sectors in catching ups (Arrow 1). Catching ups imitate the high techs produced in leading economies, and proceed to process innovation. Due to price competition, and relatively lower cost, these HT stand a higher chance of penetrating LMTs in both catching ups (Arrow 2) and leading (Arrow 4). Due to the extreme focus of catching ups on LMT, and the process of migration of LMT from developed to developing countries, catching ups stand higher chances of commercializing their LMT products with the LMT of leading countries (Arrow 3). While HT of leading economies can provide high quality technologies to the LMT in the same economy (Arrow 5), it is more probable that those technologies and products are acquired from catching ups due to lower cost, and the increasing product quality.

4.7 Conclusion, Limitations and Future Research Work

The prime aim of this research work is to differentiate HT and LMT between firms in leading and in catching-up economies. The research work proposed a theoretical framework based on Sectoral Systems of Innovation (SSI) and National Systems of Innovation (NSI). This framework included knowledge and technologies, actors and networks, institutions, sectoral dynamics and growth, and finally, sectoral transformation. Our results show that firms in leading economies are generally more focused on HT, while catching-up economies are focused on both, however with a stronger focus on LMT. Firms in catching-up economies rely on a stable technological base in all sectors, while HT firms in leading economies are witnessing a rather more unstable, dynamic technological base. This suggests that, with respect to HT, leading economies could be considered the innovator, while catching-ups are the imitators. Furthermore, HT in leading economies relies on product modularity to outsource various components probably to firms in catching-up economies. In contrast, LMT that does not demand extensive innovative capabilities is led by firms in catching-up economies who master process innovation.

This technologically driven race did not emerge by chance. Our study shows that catching-ups are putting greater emphasis on universities to produce knowledge. In addition, we found that catching-up economies provide higher accessibility to funds in order to grow the various industrial sectors, specially the LMT. This focus on LMT and export empowered the role of institutions that in turn play a key role to expand their global market share. Consequently, the role of institutions and governments with respect to regulatory policies, intellectual property protections are of high importance to firms in catching-up economies, especially in LMT.

As a result to those important steps the various agents in catching up economies have undertaken, sustainable growth is achieved, notably in the LMT. In contrast, the same growth is witnessed for the HT, with respect to firms in leading economies. While it could be argued that catching-ups are mastering LMT, evidence suggest that extensive efforts are put into HT as well using cost based strategies. Moreover, our general results suggest that catching up countries are strategizing for this sectoral evolution, renewal and transformation process, for both sectors however with a stronger emphasis on the LMT. These results call for a renewed international industrial policy that takes into consideration the various changes in the global markets, supported by Aiginger (2007), and the various OECD (2006, 2007, 2010) economic survey reports. One limitation of the analysis is that within groups of course differences exist. For instance, Taiwan and South Korea while put in the same group some differences exist between both economies, like found in Wang's (2007) work.

Our present results are limited by the collected cross-sectional data that does not give any historical or chronological aspect of studying the evolution of the various characteristics in the studied context. Our future research work will adopt evolutionary models of change for further research to understand the evolution and transformation of both sectors, with respect to leading and catching-up economies.

4.8 References

Abramovitz, M. (1986) "Catching Up, Forging Ahead, and Falling Behind" *Journal of Economic History* 46: 386-406

Abramovitz, M. (1994) "The Origins of the Postwar Catch-Up and Convergence Boom" in J. Fagerberg, B. Verspagen and N. Von Tunzelmann (eds), The Dynamics of Technology, Trade and Growth, Aldershot: Edward Elgar, 21-52

Aiginger, K. (2007) Industrial Policy: A Dying Breed or A Re-emerging Phoenix. Journal of Industry, Competition and Trade. Hingham:Vol. 7, Iss. 3-4; pg. 297, 27 pgs

Bellone, F. (2008) The role of domestic savings in outward-oriented growth strategies. Journal of Evolutionary Economics. Heidelberg: Vol. 18, Iss. 2; pg. 183, 17 pgs

Bruland, K., Mowery, D. (2005) Innovation through time. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp. 349-379

Breschi, S., Malerba, F. (1997) "Sectoral Innovation Systems: Technological Regimes, Schumpetarian Dynamics, and Spatial Boundaries" In Edquist (1997).

Cavallaro, E., Mulino, M. (2008) Vertical Innovation and Catching-Up: Implications of EU Integration for CEECs-5. International Advances in Economic Research. Edwardsville Vol. 14, Iss. 3; pg. 265, 15 pgs

Chandler, A. (1962) Strategy and Structure: Chapters in the History of the American Industrial Enterprise. Cambridge, MA: MIT Press

Cooke, P., Gomez Urgana, M., Etxebarria, G (1997) "Regional Systems of Innovation: Institutional and Organizational Dimensions" *Research Policy* 26:475-91

Edquist, C. (ed.) (1997) *Systems of Innovation: Technologies, Institutions and Organizations*, London: Printer

Edquist, C. (2005) Systems of Innovation: Perspectives and Challenges. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp. 349-379

Fagerberg, J., Godinho, M. (2005) Innovation and catching-up. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp. 514-542

Fan, P. (2006) Catching up through developing innovation capability: evidence from China's telecom-equipment industry. Technovation. Amsterdam: Vol. 26, Iss. 3; pg. 359

Freddi, D. (2009) 'The integration of old and new technological paradigms in low- and medium-tech sectors: the case of mechatronics', *Research Policy*, Vol. 38, pp.548–558.

Freeman, C. (1987) *Technology Policy and Economic Performance: Lessons from Japan*, London: Pinter.

Freeman, C., Louca, F. (2001) *As Times Goes By. From the Industrial Revolutions to the Information Revolution*, Oxford: Oxford University Press

Freeman, C., Soete, L. (1997) *The Economics of Industrial Innovation*, 3rd edn, London: Pinter

Gerschenkron, A. (1962) Economic Backwardness in Historical Perspective, Cambridge, Mass: Belknap Press.

Hsieh, C., Löfgren, H. (2009) Biopharmaceutical innovation and industrial developments in South Korea, Singapore and Taiwan. Australian Health Review. Sydney: Vol. 33, Iss. 2; pg. 245, 13 pgs

Li, J., Kozhikode, R. (2008) Knowledge management and innovation strategy: The challenge for latecomers in emerging economies. Asia Pacific Journal of Management. Singapore. Vol. 25, Iss. 3; pg. 429, 22 pgs

Lundvall, B.-A. (ed.) (1992) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London: Pinter.

Malerba, F. (ed.) (2004) *Sectoral Systems of Innovation: Concepts, Issues and Analyses of Six Major Sectors in Europe*. Cambridge University Press, Cambridge.

Mazzoleni, R. (2008) Catching Up and Academic Institutions: A Comparative Study of Past National Experiences. The Journal of Development Studies. London: Vol. 44, Iss. 5; pg. 678

Meriküll, J. (2010) The Impact of Innovation on Employment: Firm- and Industry-Level Evidence from a Catching-Up Economy. Eastern European Economics. Armonk: Vol. 48, Iss. 2; pg. 25

Mendonca, S. (2009) Brave old world: Accounting for 'high-tech' knowledge in 'low-tech' industries. *Research Policy* 38 (2009) 470-482

Nelson, R. R. (ed.) (1993), *National Systems of Innovation: A comparative Study*, Oxford: Oxford University Press.

Norma, V. (2005) Essays on university-industry collaboration, Ph.D. Dissertation, New School University, 175 pages; AAT 31

OECD Economic Surveys (2006) Upgrading Japan's innovation system to sustain economic growth. Paris: Iss. 13; pg. 127, 39 pgs

OECD Economic Surveys (2007) Challenges facing the Austrian economy Anonymous. Paris: Iss. 15; pg. 19, 24 pgs

OECD Economic Surveys (2010) Chapter 3: Need for speed: Boosting productivity growth by strengthening competition, entrepreneurship and innovation. Paris: Iss. 1; pg. 65, 37 pgs

Pavitt, K. (1984) Sectoral patterns of technical change: towards a taxonomy and a theory. *Research Policy* 13, 343-373

Robertson, P., Smith, K., Tunzelman, N. V. (2009) *Innovation in low and medium technology industries [introduction]*, *Research Policy* 38, 441-446

Santamaria, L., Nieto, M. and Barge-Gil, A. (2009) 'Beyond formal R&D: Taking advantage of other sources of innovation in low- and medium-technology industries', *Research Policy*, Vol. 38, pp.507–517.

Shin, J. (1996) *The Economics of the Latecomers: Catching-up, Technology Transfer and Institutions in Germany, Japan and South Korea*, London: Routledge.

Society of Manufacturing Engineering (2007) Still Ahead But for How Long? Manufacturing Engineering. (www.sme.org) Dearborn: Vol. 138, Iss. 4; pg. 30, 2 pgs

Tsai K., Wang J. (2009) External Technology sourcing and Innovation performance in LMT sectors: An analysis based on the Taiwanese Technological Innovation Survey. *Research Policy* 38, 470-482

Tu, C., Yang, S. (2008) National System of S&T Innovation: Dynamics of Manpower Building in a Catching-Up Economy Journal of Asia - Pacific Business. Binghamton: Vol. 9, Iss. 2; pg. 153

Van Schaik, A., Van de Klundert, T (2010) Productivity Growth and the Labour Market. SSRN Working Paper Series. Rochester

Veblen, T. (1915) *Imperial Germany and the Industrial Revolution*, New York: Macmillan

Von Tunzelmann, N. and Acha, V. (2005) 'Innovation in 'low-tech' industries', in Fagerberg, J., Mowery, D.C. and Nelson, R.R. (Eds): *The Oxford Handbook of Innovation*, Oxford University Press, Oxford, pp.408–432.

Wade, R. (1990) *Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization*, Princeton: Princeton University Press.

Wang, J. (2007) From Technological Catch-Up to Innovation-based Economic Growth: South Korea and Taiwan Compared The Journal of Development Studies. London: Vol. 43, Iss. 6; pg. 1084

Wang, H. (2008) Innovation in product architecture--A study of the Chinese automobile industry. Asia Pacific Journal of Management. Singapore: Vol. 25, Iss. 3; pg. 509, 27 pgs

Wei, J., Malik, K., Shou, Y. (2005) A pattern of enhancing innovative knowledge capabilities: Case study of a Chinese telecom manufacturer. Technology Analysis & Strategic Management. Abingdon Vol. 17, Iss. 3; pg. 355

Xie, W., Zedtwitz, M. (2010) Main characteristics of world-first innovation in catching-up countries. Journal of Technology Management in China. Bradford:Vol. 5, Iss. 2; pg. 108

Chapitre 5

THE EVOLUTION OF SYSTEMS OF INNOVATION : A PHYLOGENETIC TREE APPROACH

By Ziad Rotaba and Catherine Beaudry

Submitted to : Technovation

5.1 Abstract

Evolutionary theory has and is still offering a substantial impact to our understanding of systems of innovation. This approach that was none intentionally introduced by Joseph Schumpeter in the beginning of the 20th century did not materialize on the evolutionary level until the work of the new-Schumpeterian school. This school's fundamental breakthrough is the mutation of the innovation process from an evolutionary perspective, including the use of evolutionary metaphors and techniques. This mutation of innovation and evolution resulted into various literatures, including growth models that have been widely used to explain and study innovation and its impact on policy formulation and decision-making. This research work aims to empirically identify the differences that characterize sectoral and national systems of innovation using a phylogenetic tree approach. The resultant data from a survey that addresses firm's innovation both on the sectoral and national levels will be considered as a pool of perception practices or cultural units (meme). Hypothesizing that decision makers' perceptions follow a universal Darwinian track, a phylogenetic tree is constructed using the parsimony technique and results are analyzed. Our results show that the phylogenetic tree, using parsimony enables us to differentiate between the various sectoral and national systems of innovation being studied. This research work opens the door for the use of such techniques, adopted from evolutionary biology to classify and study the evolution of firms from cross sectional data.

Keywords: Evolution, phylogeny, parsimony, innovation, sectoral systems, national systems

5.2 Introduction

When studying the influence of time and history on the emergence of industrial revolutions, Bruland and Mowery (2005) included two important systemic approaches in viewing innovation, even though not specifically: the national and sectoral systems of innovation. Innovation is one of the prime factors responsible of the various dynamics affecting sectors and nations. Joseph Schumpeter was the first economist to clearly pinpoint the role of innovation on the formation of business cycles. The neo-Schumpeterian school led by Nelson and Winter (1982) later developed various innovation centric models to conceptualize Schumpeter's work in an evolutionary framework. The resultant work of this school contributed to the development of various models including growth and history friendly models. While such models are of high importance, a complementary approach would be an important step to enhance our understanding of the complex innovation process. Our complementary approach is to view systems of innovation in terms of practice perceptions or cultural units (meme[3]). From that stand, populations are considered to hold the various perceptions to their inner and outer spheres of knowledge, with respect to their sectoral and national systems of innovation. The inner world will represent the agent's view of the internal firm practices. The outer view will equally represent a decision maker's view to the world outside the firm's boundaries. Consequently, any decision maker's (or agent) perception will be function of the inner and outer world all together. Hence, one can argue, that when a decision maker is asked about a certain practice, his/her transmitted opinion will be his perception of the practice. These perceptions are quite important, since these are a mix of the actual nominal measures, such as profitability, and other measurable factors, together with the physiological factors that regular economic indicators usually do not absorb.

In the knowledge-based view that this paper takes, such business practice perceptions are codified by means of a questionnaire. Assuming universal Darwinism (Hodgson, 2002)[4], cross sectional traces of such practices can lead to the reconstruction of the phylogenetic tree, or 'historical' tree of firms' perceptions. The unit of analysis is cultural memes, aggregated on the population of firms that belong to either high technology (HT) or low medium technology (LMT), and in leading (i.e. developed) or catching up (i.e. developing) economies arranged in four cells of a matrix. This technique enables us to comparatively analyze the four groups of the resulting matrix in a stepwise analysis of the characteristics and see whether they stand the phylogenetic parsimony test. The use of parsimony, as a methodology to build the phylogenetic

---

[3] According to Dawkins (1976) metaphor.

[4] The main issue when dealing with universal Darwinism from an economic perspective is its incorporation of random variation: a notion that occupies the mid of the Darwinian evolution theory. While decision makers are rational, one would marginalize the probabilistic variation process. However, this can be contrasted by questioning what is really rational, and relevant to what. Furthermore, assuming that rationality is the same across industries and countries implies that agents have the same rationality and could be subject to various spectrum of information completeness. Such discrepancy would certainly affect the various economic agents' perceptions of reality. Moreover, it turns out that this variation process is not that random, as this kind of variation is proven to be also the product of environmental stress that shapes the variation process.

tree, requires the important hypothesis, in addition to that of universal Darwinism, that firms' characteristics evolve on a phylogenetic tree that minimizes the number of evolutionary steps. In other words, the version that we know of history is the most optimum. Our results show that reconstructing history, using the phylogenetic tree approach enables us to differentiate sectoral and national systems of innovations and to understand the differentiating factors between the various groups of firms.

The remainder of the paper is organized as follows: section 2 presents the theoretical background of the paper with respect to two axes: Darwin's theory of evolution in an economic context and the national and sectoral systems of innovation from an evolutionary perspective; section 3 describes the research hypotheses derived from the literature review; section 4 presents the data and methodology; section 5 provides the results; section 6 discusses the implication of these results; and finally, section 7 concludes with an outlook towards future research work.

5.3 Theoretical framework

When studying sectoral and national systems of innovation, time and history are of significant importance. This is presented in the works of Bruland and Mowery (2005) studying the emergence of the 1st, 2nd and 3rd industrial revolutions. The three revolutions can be viewed from the systems of innovation angle. For instance, the first industrial revolution, led by the United Kingdom, witnessed the development of industries such as iron, steel, coal, textile and mechanical engineering products. In the beginning of the 20th century, transforming from a position of catching-up to the leader of the second industrial revolution, Germany, and later the US, mastered large scale continuous process production that included the automobile industry, internal combustion engines, as well as oil and gas exploration machinery. Led by the US, the third industrial revolution included ICT, biotech, and pharmaceuticals, the currently identified high tech sectors. Factors characterizing the emergence of each revolution are different. For instance, the first industrial revolution depended on the role of individual inventors, and on the emerging role of institutions to foster technological change. The second industrial revolution however, witnessed the emergence of the bond between university and industry that brought the first concept of industrial in house R&D labs in Germany. The third industrial revolution was primarily based on an unprecedented governmental increase in R&D support.

Taking these industrial revolutions into perspective can inform on how various economic characteristics can shape history. The characteristics, or practices, of firms located in each nation or sector identifies the nation to be in a leading or a catching up position, and the sector, to be a high tech (HT), or a low medium tech (LMT) sector. Historically, environments in which firms are located, are a modified version of their past environments, or in biological term, of their ancestral environments. This is supported by Kubler (1982) who asserts that the current form of everything we see now, is a variant of something made in the past. This quote is not limited to technologies, but also applies to firms' practices. This argument is the root of Darwinian evolution. In evolutionary biology, biologists hypothesizing Darwinian evolution use DNA to reconstruct the tree of life of the various species. Likewise, cross sectional data collected from firms located in various sectors and nations can enable us to reconstruct a tree of life. While this temptation to map technological innovation into taxonomies that mirror the 'tree of life' has been revealed by Ziman (2000, Ch. 4), it has not materialized to date.

In order to justify the utilization of evolutionary techniques to build the phylogenetic tree, the supporting foundation of the Darwinian track of evolution is first explored followed by the systems of innovation and evolution with the associated survey characteristics.

5.3.1 Evolution

In this section, we explore the three main components of natural selection: variation, selection and adaptation (Jablonka and Ziman, 2000; Cordes, 2006). According to Maynard Smith (1986), for Darwinian evolution to take place, three properties should characterize the population being studied: First, the entities must able to multiply (i.e. one gives rise to one or two or more); Second, there should be variation of characteristics across the population being studied; Third, variation must be hereditary. Therefore, the classification of firms into groupings based on similarity with Darwinian evolution, assumes a common ancestor (Jablonka and Ziman, 2000). In our case, we have two objectives: First, to classify firms according to their characteristics; Second, to test whether a phylogenetic tree would give us reliable information about any historical indications regarding the development of systems of innovations. In our case, the genetic structure of firms (that should direct to their practices) should allow us to group them according to the various environments (sectors and economies) to which they are subject. We thus hypothesize that firms' characteristics\practices should be similar if subject to the same system of innovation. Consequently, firms with similar practices should be classified in the same group and put on a common lineage. This type of grouping is based on the hereditary principle. As a consequence, when building the evolutionary tree, branching constitutes a historical reconstruction.

Here, it is important to highlight the difference between genotype and phenotype. A genotype is what an organism holds in its own DNA structure. This DNA coding does not necessarily translate to the apparent characteristic of the organism. However, when the genotype potential is actualized, it is transformed from genotype to phenotype (an apparent characteristic). Environment plays a key role to actualize genotype to phenotype. For instance, in the case of plants, the same plants with the same genotype usually develop different phenotypes when planted in different locations (Jablonka and Ziman, 2000). In our case, perception practices should be considered the firm's 'genotype'. The aggregate of such perceptions would constitute sectors and economies aggregate genetic perceptions. Firm's 'phenotypes' are their apparent performance and measurable criteria. Therefore, the aggregate of firm perception (memes) are considered the population genetic code. This genetic code is transmitted from one environment generation to another. If the same practice is used in different economies or sectors, it should translate to a different phenotype or performance, thus justifying the classification of firms.

DNA variations are called mutations. These status changes/mutations include "an addition, deletions of bases, change in the position and the number of sequences, and changes in the number of chromosomes and data sets" (Jablonka and Ziman, 2000, p. 16). While to a great extent, these apparent changes might seem random, recent research has discovered that the assumption that the variations that occur to DNA are not 'blind mistakes' as previously thought. In other words, it shows that the variation process is not that random after all. In fact, it is strongly suggested that during evolution, changes in characteristics are subject to "environmental stress" (Jablonka and Ziman, 2000, p. 16). In addition to these environmental stresses, adaptation to scarce resources is a crucial force of evolution (Cordes, 2005). When changes occur to DNA, characteristics are inherited, while carrying an alternative characteristic or a non-functional one (Jablonka and Ziman, 2000). This argument levels the attack on universal Darwinism due to random variations. It reinforces the notion that what is explained to be random could in fact be reactions to environmental stresses. Transposing into our economic environments, variation to differentiate between leading and catching up economies, HT and LMT firms will be subject to the various environments firms are subject to.

Turning now to adaptation, evidence shows that a variety of engineering products are subject to re-occurrence due to selection pressures on the organisms, or in other words, adaptation (Jablonka and Ziman, 2000). According to David (2000), adaptation can generally take three forms. The first is the adaptation by revision: This is the pure Lamarckian track and is based on informed trial and error revision. It is basically a recursive practice. It is direct and efficient. Its disadvantage is that it needs sufficient intelligence to keep going, and might be trapped into a local minimum (due to bounded rationality for instance). The second is adaptation by selection, the Darwinian track, otherwise called adaptation by constrained variation and selection. These variations are made from a specific mechanism. It is the mechanism of trial and error or reinforcement learning. Its disadvantage is that it includes many trial variations, so it is inefficient. On the positive side, it does not need much intelligence. If variation is wide enough, it can escape the trap of local minima. Finally David (2000) adds the adaptation by coding that includes a step of Darwinian and another step of Lamarckian adaptation.

On speciation and macroevolution particularly, the definition of species and how they should be grouped is still a debate among biologists. Speciation is usually related to geographic isolation (Jablonka and Ziman, 2000). This argument is a valid argument to be used to differentiate economies and sectors. Practices, if used in different locations or sectors, will yield highly differentiable results across the various systems of innovations.

Much effort in the literature trying to map technological evolution to Darwinian evolution is actually directed to resolve the paradox between creation and evolution in a technological context. Some argue that technologies are created, hence evolution is not liable to explain technologies. Others like Dawkin will defend evolution saying that any design could be developed using a blind trial and error (the blind watch maker). Furthermore, in an effort to narrow the gap of applicability between evolution and creation, advocates of the 'Universal Darwinism theory would assert that our human cognition is the product of natural selection;

hence selection principles are to be considered (Jablonka, 2000). More importantly, with respect to technological evolution, Griffiths and Gray (1994) suggest that the unit of evolution should be the organism's development through its life cycle, not through generations (Jablonka, 2000). A central hypothesis in Darwin's theories is that populations evolve not individual organisms. This is why the unit of analysis in our case is populations rather than individuals. In our context, practices framework escapes the product or technology life cycle constraint, and thus could be more analogous to evolving Darwinian populations. As a general conclusion, there is enough "diversity and relatively blind variation in a population of technological entities to sustain an evolutionary process" (Ziman, 2000, p. 7).

5.3.1.1 Low, Medium and High Tech Sectors as Technology and Practice

Recently, some technological innovation scholars started to study technology from a cognitive angle. According to Stankiewicz (2000), technology from a knowledge perspective could be analyzed according to the following four evolutionary regimes related to our industrial sectors. In the Craft Regime, technologies are poorly standardized and with high unit costs. Technology development is gradual and no distinction exists between design and production activities. Guilds are an example of technology accumulation and learning, by transmitting knowledge and skills from one generation to another for example. Knowledge accumulation is artifact bound and local. Therefore, the design space is fragmented and is incoherent. Accordingly the potential of production is reduced based on these constraints (Low Tech). In the Engineering Regime, design is separated from production. Knowledge is codified into building blocks identified as engineering science (LMT & HT). The Architectural Regime is concerned with the design of complex multifunctional systems. Therefore, it depends on the craft and engineering regimes. Architectural development is purely about design. Therefore the designer in that case tries to absorb user's needs and design the complex technologies that fulfill their needs. It is hard to define and accumulate (LMT & HT). Finally, in the Research Regime, discovery and new products/technologies is the most basic ingredient of its design space. These regimes are natural science based, for instance biotech and pharmaceuticals (HT). The author refers to social construction of technology, organizational learning, and economics of knowledge, technological systems and systems of innovation. This is when discussing the organizational and institutional implications (which is the social dimension) of technological and cultural evolution (Stankiewicz, 2000).

Sectoral demand is subject to natural selection as well. For instance foraging strategies like the application of technology or cooperative foraging has been selected due to natural selection forces that favored behavioral strategies that economize on physical effort (Cordes, 2005). As a result the above regimes are responding to demand that is itself subject to natural selection. This demand, in the form of 'acquired wants' emerges. As a result, value is created in a certain sector. This creation of values involves cognitive learning, and consumption of knowledge about the various inputs, tools and services. Firms are on the other side, watch such sectoral changes and are fulfilling those (Cordes, 2005). Automated machinery emerged to replace man's hands and mind in production. Consequently the motivation to use technological evolution is primarily based on the need to avoid excessive physical activity and the need for physical ease.

5.3.1.2 Geography/Economies as Technology and Practice

Previously we have discussed speciation and its role into the variation of species due to isolation that we have deemed similar to practice. We concluded that it plays a major role to differentiate economies and sectors. Some researchers (Macfarlane and Harrison, 2000) have questioned the main difference between England and Japan, in terms of using of machinery for the former versus human powers for the latter until the 20th century, and the trajectory of technology deployment. Due to economic and geographical constraints they found that, in Europe, in order to solve problems, they built machines, while in Japan, they innovated in the social organization and deployment of labor. Hence "Japan led the industrious revolution, and in Europe the industrial one" (Macfarlane and Harrison, 2000, p. 89). This explains why Japan mastered its industrial organization after the World War II, and came up with its various organizational and quality strategies. While the leading economies at that time, were primarily focused on product innovation. Therefore, long-term economic development followed different sources for different nations because of differences amongst environments (Diamond, 1997). For this reason, the learning histories of people differ, and different cultural and institutional setups mandated different paces in technological progress in different economies and societies (Weber 1993; North, 1981).

From an innovation perspective, according to Constant (2000), developed countries were more advantaged compared with less developed economies for two main factors: First, higher level of resources to experiment, thus higher ability to tolerate the costs of failures and experiments; Second, positive evaluations from military, political and economic history. Consequently the evolutionary foundation of collective learning is founded in more developed countries.

This evolutionary approach enables us put more emphasis on path dependence, when analyzing systems of innovation. For instance, often third world countries strategize on acquiring technologies from developed countries to be able to catch-up. While this model is reasonable, it lacks the activity side. This is demonstrated by the artifact-activity model of Fleck (2000). Technology transfer to developing countries is not sufficient due to the lack of human element that includes tacit embodiment of mandatory knowledge. This includes the role of the highly trained, complex users that play a key role to develop and diffuse the technology (Von Hippel, 1988; Fleck, 2000).

5.3.2 Sectoral and National Systems of Innovation & Evolution

The objective of this section is twofold: first, explore sectoral and national systems of innovation from an evolutionary angle; second, explore and clarify the various factors used in the survey. Survey factors used in our analysis are based on the general framework of systems of innovation explained by Malerba (2004). Malerba's systems of innovation framework include knowledge, institutions, as well as actors and networks. Actors and networks include universities, firms, finance, and customers representing demand. These factors lead firms to witness various dynamics that lead to sectoral evolution and transformation. Beside each argument supporting each characteristic, we will refer to its number used in Table 5.4 in parentheses.

"Evolutionary theory provides a broad theoretical framework for the concept of sectoral systems of innovation" (Malerba, 2004, p. 14) because it places the sectoral dynamics that include learning and knowledge (3,4,6,9) at the center of the analysis. Consequently, various cognitive aspects affect the learning process (Nelson, 1995; Dosi, 1997; Metcalfe, 1998). Agents or population of agents are subject to bounded rationality. Hence their rationally bounded decisions are contained and bounded by various factors that include technology, knowledge base and institutional context in which agents operate (Malerba, 2004). Sutton's (1991, 1998) taxonomy for instance takes into consideration the inability of the firm to control or foresee factors that are beyond a firm's ability to invest in a certain technology or not (Von Tunzelmann, and Acha, 2005). This argument supports the 'bounded rationality' paradigm. Hence, it supports the randomness of variation that characterizes the Darwinian evolution. Knowledge therefore is able to redefine sectors boundaries (28,29), and re-shape the innovation process. Additionally, knowledge does not diffuse automatically and freely between firms (6), but has to be absorbed through time (Malerba, 2005). As a result firms facing the same environment, share the same set of learning patterns, organizational forms and behavior (Malerba, 2004). Consequently, following an evolutionary argument, sectors should differ clearly (Pavitt, 1984) across those various factors we will later introduce.

Evolution, as discussed, is generally about variation and natural selection. Malerba (2004, 2005) identifies the evolutionary approach on three basic axes: variety creation (technologies, products, and firms), replication (promoting inertia and continuity) and selection (reducing the variety and discouraging ineffective utilization of resources). Variety creation includes products (15,16), technologies (7,8,14,26), institutions (10,11,12,20), firms, strategies (17,19,25,30,31,32) and behavior. The severity of selection is sector dependent (Malerba, 2004). Consequently, new knowledge and technologies are created (2,4,5,6,7,8,9) (Nelson and Rosenberg, 1993) thus contributing to sectoral system differentiation. Additionally, new firm entry, with new products, technologies (25), know-how, knowledge, as well as universities (3,4) and sectoral institutions add to this sectoral differentiation (Audretsch, 1996; Geroski, 1995; Malerba and Orsenigo, 1999). Consequently, the evolutionary approach that reinforces the notions of selection and variety generation considerably better explains industrial dynamics and sectoral transformation of sectoral systems (24,27,28,29). The evolutionary approach also includes beliefs, objectives and expectations (Malerba, 2005).

This co-evolution and transformation of sectoral systems could occur on the technological regime, learning regimes or patterns of innovation (Malerba, 2004). Innovation activities might shift from a Schumpeter mark I to mark II or vice versa. The knowledge base might change incrementally (18) or radically (25). In the case of incremental increase (18) in the knowledge base, a dominant design emerges and large enterprises dominate (Utterback, 1994). In the case of breakthrough knowledge, however, new technology producing firm entries are encouraged (Jovanovic and MacDonald, 1994; Tushman and Anderson, 1986; Henderson and Clark, 1990; or on the user\demand side,Christensen and Rosenbloom, 1995). Therefore according to Malerba (2004), this co-evolutionary process is sector specific and affects various elements including technology, demand (1,2), the knowledge base (3 to 9), and learning processes, as well as firms, non-firm organizations and institutions.

Case studies of high technology (HT) sectors reviewed by Malerba (2004) demonstrate the following. Interaction between knowledge (3 to 9), actors (1 to 9) and institutions (10,11,12,20) shaped the evolution of the system of innovation in the pharmaceutical sector. Weaker protection (10,11,12) induced imitative strategies (11), and stronger ones led the Italian generics industry to disappear in this sector (McKelvey *et al.*, 2004). Oligopolistic structures started in the telecom sector due to the separation of telephony and broadband. However, the convergence motivated a fluid market structure, with new actors and users (1,2). Open standards were created and new actors rose such as ISP and ICPs[5] in the telecommunication sector (Edquist, 2004). Growth of software products emerged due to the role of open standards (15) and open source approach, various licensing agreements emerged in the software sector. Generic products that hold customization utilities (14,15,16) have emerged. Internal firm specializations (9) emerged to this need for providing highly customizable products (15,16) in this sector (Steinmueller, 2004).

Case studies of low and medium technology (LMT) sectors also reviewed by Malerba (2004) demonstrate the following. Technology (7,8,14), demand, markets and institutions shaped the co-evolutionary process in the chemical sector (Cesaroni *et al.*, 2004). Environmental issues further shaped the co-evolutionary process in this sector. Developed countries have observed the rise of environmentally safe products. Governments (10,20,21) imposed regulations (10,11,12) to minimize pollution. Firms in the sectors used process innovation (18) to make their products greener. Demand from advanced customers (automotive, aerospace and defense) (1,2) shaped the machine tools industry, thus incremental innovation became dominant. Patenting (10,11,12) has

---

[5] Internet Service Providers (ISP) & Internet Content Providers (ICP)

been growing strongly in recent years. Furthermore, computer scientists became more needed in this sector (Wengel and Shapira, 2004).

Mowery and Nelson (1999) study the long-term evolution of various sectors over time and across countries. They demonstrate that co-evolutionary processes differ greatly across sectors. Some are motivated by sales growth (22,23) and radical product development (25), while other sectors are mainly dependent on technologies (7,8,14), demand, institutions and firm organization as well as strategy. This process of co-evolution between the different sectoral agents is sector specific and path dependent (Malerba, 2004).

This interplay between sectoral systems and national systems is therefore inevitable. While sectoral systems could be generally invariant, national systems are variant according to Malerba (2004) as well as Breschi, Malerba and Orsenigo (2000). This is evident for instance in the case of the pharmaceutical sector (HT) (McKelvey *et al.,* 2004), where the innovation process differs across countries due to patterns of competition and market structures. Furthermore, in the pharmaceutical sector, product approval regulation provided incentives for more innovative strategies for capable firms and countries. Differences across countries according to Malerba (2005) in sectoral systems have considerably affected countries performance. An additional example is in the semiconductors industry, where the evolution of the industry has been different, depending on the countries from which they emerged. Consequently, environment and conditions are different across sectors and economies that hold different institutions.

5.4 Research Hypotheses

This section targets to build the testable research hypotheses. The major research hypothesis targets two main areas. The first is related to the first part of our literature review, elaborating on how far one of the methodologies used (in our case parsimony technique) can explain the evolution of both national and sectoral systems of innovation and hint towards a working model of universal Darwinism. Furthermore, we test whether a numerical example stands the parsimony test, in an evolutionary perspective. The second hypothesis targets the details of sectoral and national systems of innovation evolution if the first hypothesis is validated.

An important *a priori* emanating from our literature review is that technology and practice has been reduced to knowledge. This definition fits the various schools of thought including evolutionary economics and epistemology. Consequently, the use of knowledge perfectly fits the description of cultural memes that we consider the response to the research questionnaire. As a result, universal Darwinism is justified, with all its previously explained properties.

Hypothesis (H1): National and Sectoral systems of innovation, when quantized, are identifiable and evolve parsimoniously.

In other words, the evolution of systems of innovation follows a Darwinian Track. In a sense, each of the four groups of firms (HT or LMT in Leading or Catching ups), will hold a slight change from their ancestral environment. As a result of this common ancestral relationship, it is anticipated that firms belonging to the same group will more probably join the same ancestral nodes. Furthermore, since the parsimony technique is used, the evolution of such groups should follow the most optimum path, i.e. the total number of steps for the characteristics to evolve should be the minimum.

Hypothesis (H2): Leading Economies are highly differentiable from Catching up economies.

Similarities between sectors are however anticipated. Therefore, based on the sectoral systems of innovation argument, we subdivide Hypothesis H2 into two sub hypotheses:

Hypothesis (H2.1): LMT in Leading Economies are similar to LMT in Catching ups and the same is true of HT in Leading and Catching up Economies.

The innovation process is highly differentiable across countries/economies due to the various patterns of competition, market structures and institutions (McKelvey *et al.,* 2004; Malerba, 2004, 2005). On an evolutionary level, this differentiation between various economies due to differences in environments is supported by Diamond (1997), Weber (1993), North (1981) and Cordes (2005). Governments provide a supporting role to foster innovation, as in the case of Taiwan (Chen, 2009). LMT activities are shifting from industrialized to newly industrialized countries (Robertson *et al.,* 2009). Supporting Gerchenkron's (1962) view, financial institutions and governments play a key role in the catching-up process (Shin, 1996; Wade, 1990). This support is primarily directed towards increasing investment in R&D in catching ups economies, and higher support to university based knowledge production systems (Fagerberg and Godinho, 2005).

Hypothesis (H2.2): High Tech (HT) are highly differentiable from Low Medium Tech (LMT) Sectors

This differentiation is dependent on the severity of selection, and is sector dependent (Malerba, 2004) and is related to firm entry, development of new products and technologies, know-how, knowledge, universities, and sectoral institutions (Audretsch, 1996; Geroski, 1995; Malerba and Orsenigo, 1999). HT firms should be characterized with a more efficient absorptive capacity, (Grimpe and Sofka, 2009) as HT firms are primarily seeking to develop knowledge internally, while LMT firms utilize external collaboration and interactions with customers and suppliers (Santamaria *et al.*, 2009; Tsai and Wang, 2009). HT is serving customers with more complex needs than LMT.

Breakthrough innovations characterizing the HT sector will motivate firm entry (Jovanovic and Macdonald, 1994) and this should reflect on the user/demand side as well (Christensen and Rosenbloom, 1995). On the strategy side, HT firms are differentiation oriented, while LMT are primarily cost centered. Furthermore, HT use product innovation, while LMT are more process oriented (Ghosal and Nair-Reichert, 2009; Santamaria *et al.*, 2009; Heidenriech, 2009).

5.5 Data and Methodology

5.5.1 Data

Data included in our analysis is composed of 545[6] firms of the Managing Innovation in the New Economy (MINE) database. The database data is cross-sectional and decision makers perceptions are represented by a 7-point Likert scale, where ‘one’ denotes the respondent disagreement with the statement and, at the other end, ‘seven’ implies a ‘totally agree’ response. Firms are categorized in HT or LMT according to their primary sector of activity and the

---

[6] The complete sample of 700 firms will be used for comparison purposes because it contains firms that cannot be classified into the matrix of Table 5.1

American Industry Classification System (NAICS) code. Sectoral systems could be examined broadly or narrowly. According to Malerba (2005), the broad analysis allows the capture of all interdependencies and linkages related to the sectoral transformation, while a narrow analysis allows the testing of certain specific relationships. This is why we have chosen HT and LMT as a broader sectoral definition. Furthermore, firms are grouped into two groups, leading and catching up economies. Leading economies in our sample include firms originating from Canada, France, the UK and the USA. Catching up economies include China, Taiwan, South Korea, and Peru. Consequently, any of the 545 firms included in the studied sample should belong to 1 of the 4 groups shown in Table 5.1.

Table 5. 1 Sectoral and National Classification

HT (Leading versus Catching up) (Group 1)	**LMT** (Leading versus Catching up) (Group 2)
Leading (HT versus LMT) (Group 3)	**Catching up** (HT versus LMT) (Group 4)

5.5.2 Methodology

The main methodology utilized in this paper to infer the phylogeny is parsimony. Generally, parsimony indicates that simpler is better. In a systemic context, the parsimony technique is the applied heuristic algorithm to Ockham's razor, a British logician who arguing that entities must not be multiplied beyond necessity (according to Merriam Webster definition). According to Felsenstein (2004, p.139), Gafney (1979, p. 98) stated that "[i]t seems to me that parsimony, or Ockham's razor is equivalent to logic or reason because any method that does not follow the above principle would be incompatible with any predictive or causal system". Wiley (1981, p. 111) adds that "with no external criterion, we are forced to use parsimony to minimize the number of add hoc hypotheses (Popper, 1968, p. 145). The result is that the most parsimonious of the various alternates is the most highly corroborated and therefore preferred over the less parsimonious alternate".

The use of Parsimony could be seen as a generalization that most economists would avoid. Similarly, Chandler's pioneering work analyzing the history of the American enterprise tried to seek generalizations that most historians would avoid as well (Nelson, 2000). Furthermore, as argued by Hull (1988), "in order for selection process to operate the entities must be organized into populations integrated through time by descent" in (Fleck, 2000, p. 250).

As explained, the parsimony technique is a heuristic that seeks to deduce a phylogeny based on the minimum number of evolutionary steps to represent species with known characteristics. Parsimony defenders often have criticized the statistical inference technique to infer phylogenies. The first area of criticism is that statistical inference requires knowing too much about the evolutionary process (Farris, 1983; Felsenstein, 2004). Furthermore, evolutionary events are historical and hence not repeatable, as Kluge (1997) asserts that "[a]s an aside, the fact that the study of phylogeny is concerned with the discovery of historical singularities means that calculus probability and standard statistics cannot apply to that historical science".

The philosophy of parsimony was first introduced by Edwards and Cavalli-Sforza (1963) as an evolutionary tree that includes "the minimum net amount of evolution" (Felsenstein 2004, p. 126). As a result, the tree with the minimum number of evolutionary steps is considered the most parsimonious tree. For one proposed tree, each number of steps is calculated for each character and summed up to the total number of evolutionary steps. Heuristics then are used to search in the tree space for the best tree that holds the minimum number of evolutionary steps, using branch and bound (first used by Hendy and Penny (1982) to infer phylogenies). Two algorithms are generally used to count the evolutionary changes; the Fitch and Snackoff algorithms, both of which are known to be giving the same results (Felsenstein 2004). To imagine the level of complexity, for n number of firms, the number of possible trees is $(2n\text{-}3)!/2\char`^n\text{-}2(n\text{-}2)!$, where n is an integer greater than 1, and assuming a bifurcating tree (Felsenstein, 2004).

In our analysis, a characteristic is binary coded, taking the value '0' if a characteristic exists, or '1' if does not. Characteristics evolution is bidirectional, meaning a trait could evolve from 0 to 1 or vise versa. In our Likert scale, decision makers' perceptions equal or less than 3 is coded as 0 and 1 otherwise. This architecture allows putting more weight on characteristics that generally do not exist. The parsimony technique allows first, to test our primary classification, and second, if the classification is correct, to test which characteristics are influential in the evolution of systems of innovation. In the parsimony model, the tree with the minimum number of evolutionary steps is selected. In order to reach the optimum tree, 138 trees appear in the solution space, of which the most optimum is selected. It is important to note, that we have chosen the Wagner parsimony[7] that allows a characteristic to change its status from 1 to 0 or the opposite. Additionally each characteristic is considered to be independently evolving.

The intermediate nodes in the tree are transition nodes of ancestral environments. In the context of this research, our environment is classified from the perspective of sectoral and national systems of innovation. Therefore, by using parsimony on the classification level, we will infer that ancestral environments will be the environments that most resemble the current classification. By examining the important transitional nodes, we can determine which characteristics 'were' influential to distinguish the various branching that lead us to the categorization of industries and national economies (LMT vs. HT and catching up vs. leading economies). By choosing parsimony, it is necessary to consider environments that we can currently study on the cross sectional level, as a derivation of previous systems of innovation with a slight variation. The minimum number of variations across characteristics will group certain firms together, which will constitute their ancestral environment in the various depths of the tree.

5.6 Results & Analysis

Running parsimony on our data yields a tree, shown in Figure 5.1 , which generally distinguishes 4 clusters of firms (on the leaves of the tree). In addition to the 4 identified groups of firms

[7] In our analysis, the 'Pars' method from the PHYLIP package (Version 3.69) is used. The parsimony method is used (using Pars.exe in our case), will use Wagner parsimony, which is a method that allows multiple states, and allows changes among the states. According to Felsenstein (2004), the Wagner method originated from Eck and Dayhoff (1966) and Kluge and Farris (1969). For the display of Figure 5.1, the Dendroscope software (Version 2.3) developed by Huson *et al.* (2007) is used. For the output of Tables 5.2, 5.3 and 5.4 the Mesquite software (Version 2.71) (developed by Madisson and Maddison, 2009) is used to track the characteristics evolution across the most parsimonious tree.

(delineated in four boxes) and their architecture, Figure 5.1 shows 2 principal transition nodes labelled A' and B'.

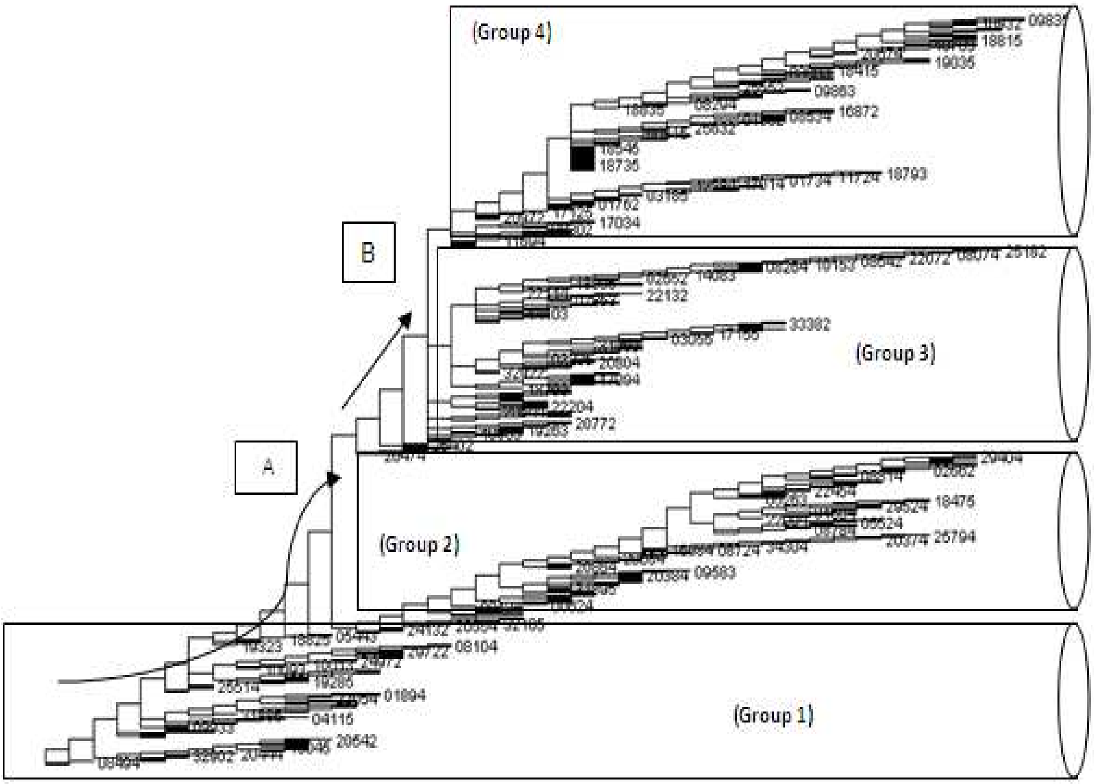


Figure 5. 1 Primary resulting phylogenetic tree with the unidentified 4 groups

In the resulting tree, Group 1 is at the root. Transition to groups 2, 3 and 4 are established by following the transition arrow *A* of the schematic version of the tree presented in Figure 5.1. At the head of arrow *A*, Group 2 emerges independently from Groups 3 and 4, which are subsequent to the transition arrow *B*. This suggests that the main characteristics of Group 1 were the prime characteristics from which the rest of the groups emerged and 'evolved'. After evolving following arrow *A*, one additional evolutionary step gave 'birth' to Group 2 and three additional steps generated Groups 3 and 4. Nodes A' and B' are transitional nodes: node A' is the resulting evolutionary transition from Group 1 to Group 2; from A', the transition arrow *B* leads to node B' from which Groups 3 and 4 evolved.

We now turn our attention to identifying the composition of the groups, and the values of the 425 nodes with respect to the 32 attributes that characterise each firm on the tree. Let us first examine the resultant tree node values without taking the highlighted tree into consideration. Table 5.2 presents the number of 1s and 0s for each node. The third column (titled ‘1’), counts the number of nodes for which each of the 32 characteristics is important (value 1) and the fourth column shows the equivalent proportion (%) of nodes. The seventh and eighth columns count the number of 0s, i.e. the number of nodes for which the characteristics are not important (value 0), and the equivalent proportion (%) of nodes. We have labelled the nodes that could take the value 0 or 1 without affecting the tree structure as 0.5; as we will see later, these nodes are not very informative because they do not appear on any transition nodes and their sample size in the tree never exceeds 3% of the total number of nodes for any characteristic, for the 500+ firms (the focal sample of analysis). In order to test the consistency of the analysis, we have used two different samples in our database, one of 545 firms (500+ or the main sample) for which the results are presented in Table 4.2 and the other consisting of 736 firms (700+), which is not shown in the table. In the eleventh column of Table 4.2 is the number of evolutionary steps that were necessary for the 32 characteristics to evolve independently on the tree. In other words, each characteristic had to go through these numbers of steps in order to represent the whole population (545 firms) on the most parsimonious tree.

The above factors give us a general idea of the dominant characteristics, i.e. a large number of 1s for a particular characteristic across the evolutionary tree hints that this characteristic do not differentiate among firms nor between the four identified groups, i.e. the sector and the economy in which this firm operates. In contrast, an equivalent mix of 0s and 1s in the characteristics’ importance for the node suggests a more dynamic characteristic and presumably allows more differentiation between the 4 groups. Furthermore, the number of evolutionary steps per characteristic provides an idea of the stability zone for each characteristic. In other words, the higher (lower) are the number of steps, the more dynamic (stable) is a characteristic. In Table 5.2, we have segmented the characteristics into 4 groups, the top 10 (the most stable characteristics), the bottom 10 (the most dynamic characteristics), and the middle 2 groups, each with 6 characteristics, resulting in 32 characteristics.

Char.	Factors	1	%	0.5	%	0	%	500+ Firms	700+ Firms	Evo. Steps	AvgEvo.Steps
9	New knowledge results from the gradual accumulation of experience inside firms	414	97%	0	0%	11	3%	9	9	40	
1	Customers provide significant expertise bout how our products operate	393	92%	0	0%	32	8%	1	14	56	
15	Products must interconnect with other products to have value for customers	390	92%	0	0%	35	8%	15	2	36	
2	Customers served by firms in our sector have very complex needs	388	91%	0	0%	37	9%	2	15	29	
14	We use many different technologies and technical solutions in our products	385	91%	11	3%	29	7%	14	30	40	
16	The operation of our products relies on the operation of many other technical systems	380	89%	2	0%	43	10%	16	1	47	
17	Large unit costs reductions can be obtained by increasing scale of operation	377	89%	2	0%	46	11%	17	**5**	45	
19	Most of the products of our sector face sever cost constraints	375	88%	3	1%	47	11%	**19**	16	43	
30	Established competitors constantly challenge our positions	375	88%	2	0%	48	11%	30	17	50	
13	Technologies produced in our sector are used for a variety of applications	363	85%	7	2%	55	13%	**13**	**31**	60	44.6
5	Our sector continually integrates many new systems and equipment	359	84%	5	1%	61	14%	**5**	**19**	49	
31	Myriads of actions by our rivals continually erode our advantage	348	82%	5	1%	72	17%	**31**	7	46	
7	New technologies build on the latest technologies of other firms in the sector	342	80%	4	1%	79	19%	7	**13**	61	
32	Our products are constantly under attack from low cost substitutes	335	79%	2	0%	88	21%	**32**	27	62	
3	Knowledge production in the academic fields relevant for our sector is very intense	330	78%	0	0%	95	22%	3	**6**	53	
27	External factors are forcing unpredictable transformation in our sector	329	77%	2	0%	94	22%	27	3	35	51
8	All firms in our sector rely on the same stable technological base	324	76%	1	0%	100	24%	8	**32**	58	
28	The boundaries of our sector are undergoing a major redefinition	312	73%	1	0%	112	26%	28	28	48	
6	New knowledge result from intense interactions between firms	311	73%	2	0%	112	26%	**6**	23	60	
23	Sales in recently opened niches within our sector grow extremely fast	309	73%	6	1%	110	26%	23	12	51	
18	Improving production processes brings much higher returns than product innovation	308	72%	7	2%	110	26%	18	8	58	
12	Intellectual property protection enables firms to capture all the value from innovation	295	69%	2	0%	128	30%	12	18	63	56.3
10	Regulatory approval is a critical prerequisite for commercializing a new product	286	67%	0	0%	139	33%	10	4	54	
4	Our sector contributes a lot of data, ideas, and paper to academic research	277	65%	4	1%	144	34%	4	10	53	
26	Technological frontier advance very rapidly in our sector	276	65%	0	0%	149	35%	26	29	45	
24	The pace of change of sector very fast compared to others	273	64%	3	1%	149	35%	24	26	48	
29	The sector undergoes significant development that nobody anticipated	252	59%	6	1%	167	39%	29	24	62	
22	Sales grow very fast compared to other sectors	241	57%	0	0%	184	43%	22	22	59	
11	Time and recourses deter me too innovation	218	51%	4	1%	203	48%	11	11	46	
25	Entry with breakthrough innovations	207	49%	0	0%	218	51%	25	25	53	
20	Government allocating resources	176	41%	2	0%	247	58%	20	20	59	
21	Ease of Startup funds	146	34%	4	1%	275	65%	21	21	74	55.3

Table 5. 2 Factors ranked from the highly dominant (Existent=1) to the highly mixed between 1 and 0

Table 5.2 provides important information in columns nine (500+ sample) and ten (700+ sample[8]). First, the ranking in terms of decreasing dominance of the characteristics for each of the 4 groups is almost identical for the two samples (500+ and 700+), with the exception of the factors marked in bold. This means that the obtained tree is very stable. In the first group, there are 2 un-matched characteristics, which appear further down in the 700+ ranking, in the second group there are 3, and in the third group there is 1 un-matched characteristic. The group that holds the exact match between the two samples is the last group, which is the group with the most equivalent number of 0s and 1s. The 700+ firm sample is only used for the means of comparison with the 500+ sample. The 500+ sample is used in our analysis, since it contains data about leading and catching-up economies, not properly represented by the 700+ sample. Furthermore, the smaller is the average number of evolutionary steps (last column of Table 5.2), the more dominant is the group of characteristics throughout the tree. The higher number of evolutionary steps increases with a more equal mix of 0s and 1s, i.e. with the increasing importance of 0s with respect to 1s, the higher the number of evolutionary steps a characteristic has to go through in order to reach its final classification (in one of the four groups).

Second, a higher number of 1s is associated with the following characteristics: knowledge accumulation inside firms, understanding customers' needs, cost, competition and mastering technologies in terms of deployment, integration and development. These characteristics are therefore dominant across all firms, and hence from an evolutionary perspective, all intermediate nodes with such characteristics will have a value of 1, which do not allow differentiating between sectors or economies. Since these factors are very common regardless of the associated system of innovation, it indicates that these factors would not provide an efficient way to classify firms into their systems of innovation, whether on the country or sector levels. All firms in our

---

[8] Characteristic 9 (new knowledge…) occupies the first rank, i.e. with the most number of 1s for the tree nodes, for both samples. In the tenth column, the second highest rank is occupied by characteristic 14 (different technologies…), followed by characteristic 2 (customers served by firms…). As such, column ten is only presented to compare the ranking obtained from the 500+ and 700+ samples. The other results presented in the table refer to the 500+ sample.

sample more or less similarly strategize internally, regardless of the system of innovation within which they are located.

As the last group (with the most equal share of 0s and 1s) suggests, firms' perception of their external environment is interesting to monitor. In a sense, it conveys that while firms could generally be strategizing internally according to the same principles, they have different external environments to interact with: regulation, knowledge generated from interaction with universities, and various external dynamics such as sales growth, intellectual property protection, and entry with breakthrough innovation. The highest number of 0s is directed towards the easiness of obtaining start-up funds (characteristic 21), and government resource allocation (characteristic 20). Dynamics resulting from these external factors are primarily due to nation specificities with respect to allocation of funds to foster R&D. This could also be due to sector-focused policies, where for instance HT firms are expected to have higher resources allocated for R&D than LMT. Hence these factors are expected to be responsible for the differentiation between firms on the systems of innovation level. Whether it be on the national or sectoral levels, the structure of the tree will enable us to further explore this dimension. The same applies for the bottom 10 characteristics. This general examination of the results is extremely important for entities such as the OECD that rely on classification. It tells that classifying firms according to investment in internal R&D might not be the most appropriate methodology. Instead, governmental resource allocation and spending maybe considered as a prime-differentiating factor between sectors and economies.

Each firm is labelled with a code that enables its identification on the tree. Thus, counting the number of firms belonging to each of the 4 categories described previously allows us assign and identity each of the four groups on the tree. Of course, each of the identified groups will contain firms from the 4 predefined categories, as well as other firms that do not belong to the studied category. Table 5.3, shows the number of firms of each category in each of the identified groups. Due to differences in the sample sizes of LMT and HT, it is evident that the percentages will be more dominated by the LMT sample. In order to overcome this, we have considered the percentage of each group compared with its own group (shaded in grey). For instance, for firms belonging to the high tech sector in leading economies, the highest percentage across all groups, is located in Group 1 (G1). The high tech sector in catching up economies is more dominant in Group 3 (G3). The LMT in leading economies is dominant in G2 and LMT in catching up economies in G4.

Table 5. 3 Identification of groups according to HT, LMT industries and Leading, Catching up economies

Groups	Start Nodes	Intermediate Nodes	2-G1 (HT Leading)	%	3-G2 (HT Catching)	%	4-G3 (LMT Leading)	%	5-G4 (LMT Catching)	%	Total
G1	1	2-13	24	25%	19	20%	34	35%	19	20%	96
G2	A'	15-22	15	12%	7	5%	84	65%	24	18%	130
G3	B'	h-k	28	23%	25	21%	34	28%	34	28%	120
G4	B'	d-g	44	22%	37	19%	43	22%	74	37%	199
Total			111		88		195		151		545

This classification allows us to associate the most dominant group of each category to each of the four branches as we first illustrated in Figure 5.1. The resulting schematic tree is shown in Figure 5.2.

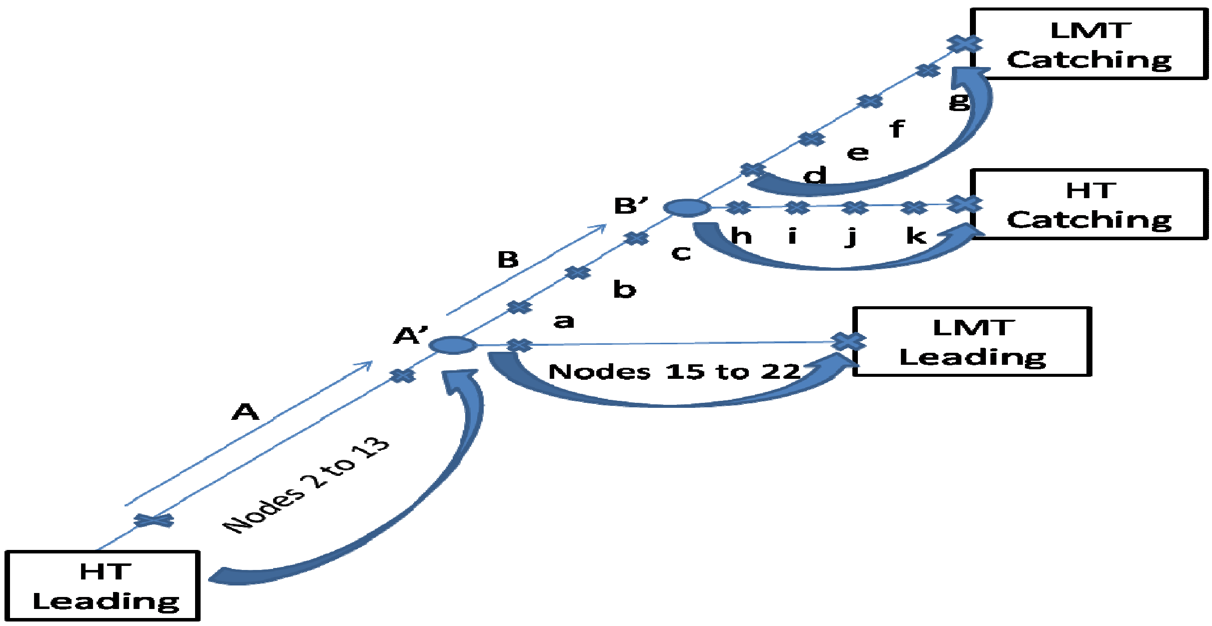


Figure 5. 2 The final abstracted results based on parsimony

The successful identification of the categories on the most parsimonious phylogenetic tree, contributes to Hypothesis one (H1). Figure 5.2 illustrates that HT firms in leading economies are at the root of the phylogenetic tree. This suggests that, considering the most parsimonious tree, high tech sectors in leading economies can be considered as the origin of the practices for the rest of the sectors/economies. Reconstructing the tree in such a structure corresponds to the emergence of the high tech sectors in leading economies. The other sectors/economies covered by the survey derive their best practices based on the best practices emerging from HT in leading economies. This result hints towards the renewal, transformation and migration of LMT from leading economies to catching-ups. Heindenreich (2009), for instance, has found that LMT is shrinking in the case of Western Europe. Catching up economies, however, follow Robertson and Patel (2007) rules that hints towards the complementary nature between HT and LMT: in short a nation excelling in producing HT should accordingly excel in LMT technologies\products. This renewal and transformation process could be primarily motivated by the dominance of the best practices that the high tech sectors in leading economies adopted and pushed or leaked out. In order to reach the node A' of Figure 2, arrow *A* goes through 12 nodes, or evolutionary steps, to reach the first transition node, where the LMT leading sector branches out. This indicates that the next sector/economy that was influenced by practices of HT firms in leading economies was the LMT in leading economies. This result reinforces the importance of national systems of innovation, to support the renewal of mature sectors.

Arrow *B*, goes through four transition nodes to get from node A' to node B'. So compared to one step to reach LMT in leading economies, three additional transitional steps were needed to evolve and adopt the best practices of leading economies in catching up economies. Again this result reinforces the previous argument concerning national systems of innovation. This hints towards the migration of LMT activities\practices from leading towards catching-ups for instance (Heindenreich, 2009; Robertson et al., 2009) Following the same line of argument, one additional step was needed for these best practices to dominate catching up economies, further supporting the national systems of innovation argument. It is noticeable however that, on the tree, there is no differentiation between sectors as much as in the leading economies. Therefore, one would argue that in leading economies the difference between the two categories of sectors in terms of practices is highly differentiated. The same is not true in catching up economies, which probably see, or treat, both types of sectors equally with no special attention to one sector compared to the other.

Now that the groups are identified, number of transition nodes identified, we turn our attention to the characteristic changes with respect to the nodes and identified sectors. Table 5.4, represents the evolution of the characteristics across the nodes leading to each of the 4 groups. Transition nodes are identified with T at the top of the column. The first column is the origin node of any sectoral transformation/evolution. For instance node A', was the source of transition for the LMT sector in leading economies, but also the source of additional transition periods (from nodes a, b, c to node B') that led to the catching up economies sectors. Therefore the first node to reach these sectors was node B' that then branched out into node d in the case of LMT catching up economies, and node h in the case of HT in catching up economies. The implied evolution of each characteristic is read in the table from left to right, going through the sectors, highlighted above the node labels, or transitional steps, which includes multiple nodes in the case of catching ups (a, b and c). In dark grey highlight, are shown the characteristics that had 1s across all sectors and transition nodes. When comparing these rows with the top group in Table 5.2, only one characteristic (15, product interconnect-ability, with only one 0) does not appear in the first group of Table 5.2 and additional transitional nodes with only 1s appear forcharacteristics 5, 6, 7, 27, 28, 31, and 32, which all appear in the top three categorisations of Table 5.2.

C/N	Factor	HT Leading												T	LMT Leading								T	Transition			T	LMT Catching				T	HT Catching			
		2	3	4	5	6	7	8	9	10	11	12	13	A’	15	16	17	18	19	20	21	22	A’	a	b	c	B’	d	e	f	g	B’	h	i	j	k
1	Customer and product operation	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
2	Customers needs complexity	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
3	Intensity of knowledge production in univ.	0	0	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
4	Sectors contribution to scientific knowledge	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	0	0	0	0	**1**	**1**	1	1	**1**	**1**	0	1	1	**1**	**1**	1	1	1
5	Sectors integration	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
6	Knowledge production through interaction	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
7	Technologies build on latest technologies	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
8	Firms reliability on a stable tech. base	0	0	0	0	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	0	0	**1**	**1**	1	0	1
9	Knowledge accumulation from inside the firm	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
10	Reg. approval critical for commercialization	0	0	0	0	0	0	0	0	0	0	1	1	**1**	**1**	1	1	1	1	0	0	0	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
11	Time and resources deter me too innovation	0	0	0	0	0	0	0	1	1	1	1	1	**1**	**1**	1	1	1	1	0	0	0	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
12	IP protection to capture value	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	0	0	0	0	0	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
13	General Purpose Technologies (GPT)	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
14	Utilization of diff. tech. in firms products	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
15	Products interconnectability	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	0
16	Products dependability	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
17	Cost reduction	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
18	Process innovation	0	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
19	Cost based competition	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
20	Government allocating resources	0	0	0	0	0	0	1	1	0	0	0	0	**0**	**1**	1	1	1	1	1	0	0	**0**	**0**	0	0	**0**	**1**	1	1	0	**0**	**0**	0	0	0
21	Ease of startup funds	0	0	0	0	0	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	0	0	0	**1**	**0**	0	0	**0**	**0**	0	0	1	**0**	**0**	0	0	0
22	Sales growth	1	1	1	1	1	1	1	1	1	1	1	1	**0**	**0**	0	0	0	0	0	0	0	**0**	**0**	1	1	**1**	**1**	1	1	1	**1**	**0**	0	0	0
23	High sales growth through new niches	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	0	0	0	0	0	0	0	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	0	1	1
24	Comparative high pace of change	1	1	1	1	1	1	1	1	1	0	0	0	**0**	**0**	0	0	0	0	0	0	0	**0**	**0**	0	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
25	Entry with breakthrough innovations	0	0	0	1	1	1	1	1	1	1	1	0	**0**	**0**	0	0	0	0	0	0	0	**0**	**0**	0	0	**1**	**1**	1	1	1	**1**	**1**	1	1	1
26	Rapid advancement of technological frontier	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	0	0	0	0	0	0	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
27	Unpredictable transformation by externalities	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
28	Sectoral boundaries redefinition	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
29	Anticipated sectoral development	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	0	0	0	0	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
30	Incumbent competition	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
31	Competition eroding advantage	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1
32	Cost competition	1	1	1	1	1	1	1	1	1	1	1	1	**1**	**1**	1	1	1	1	1	1	1	**1**	**1**	1	1	**1**	**1**	1	1	1	**1**	**1**	1	1	1

Table 5. 4 The evolution of characteristics passing by the transition nodes and leading to the four identified groups

5.7 Discussion

From Table 5.4, we can see that the dominant characteristics (populated with 1s highlighted in dark grey) are related to customers, and fulfilling their needs with the various complexities incorporated with such interactions. Cost and competition strategies, technological superiority and the general understanding of external environmental dynamics are the last dominant characteristics. These represent the most stable characteristics throughout the sample. These results suggest two important findings. On the sectoral level, results suggest that the differentiating element is not that obvious between HT and LMT with respect to various factors as previously found by Malerba (2004). Furthermore, the interaction between firms that characterized most LMT (Santamaria *et al.*, 2009; Tsai and Wang, 2009) is dominant for HT as well. In addition, knowledge development from within the firm is dominant regardless the sector.

This supports the argument that absorptive capacity of firms in HT and LMT firms is well developed in both but probably for different reasons. For instance, Grimpe and Sofka (2009) suggested that LMT firms' absorptive capacity is focused on market inputs, while for HT firms it is focused on deep technological knowledge and expertise. Furthermore, while it is predominantly thought that LMT firms are more cost driven (Von Tunzelmann and Acha, 2005), HT firms seem to be following a recent cost focus as well. Process innovation that is dominantly thought to be a main characteristic of LMT firms (Ghosal and Nair-Reichert, 2009; Santamaria*et al.*, 2009; Heidenreich, 2009), is seen to be a dominant characteristic of HT firms as well (see characteristic 18 in table 5.4). On the national level, the above findings demonstrate the effect of globalization on business practices, with respect to the above characteristics. For instance, the increasing complexity in consumer tastes, and its international expansion (Mendonca, 2009) would put pressures on firms to perform in a certain unified way. The above results suggest a renewal and transformation of the two studied sectors regardless the national system of innovation within which they reside.

The second step consists in analyzing the changing characteristics (from 0 to 1 or vice versa) and how they impacted the formation of the 4 groups. In Table 5.4, 0s are highlighted in light gray. From a bird's eye view, apparent dynamics occur after the transition node A', the origin of the formation of LMT/leading and both sectors of the catching ups. Furthermore, if we look from the characteristics point of view, we can see that most of the changes happen from characteristics 20 to 23, dedicated to the measure of growth, in addition to some other scattered characteristics. Each changing characteristic will be examined from the top of the table, according to 4 groups: knowledge production, factors influencing innovation, resources inflows and growth, and finally strategy and competition.

The first group relates to knowledge. Characteristic 4 explains the importance of the bond between the sector and the academic field. It is remarkable that this factor has dropped in importance in LMT in leading economies, while the opposite happened in catching up economies for both sectors; this supports the findings of Fagerberg and Godinho (2005) and Tsai and Wang (2009). Furthermore, in catching up economies the perception of firms to be relying on a stable technological base is predominantly nullified, especially in the LMT sector. This suggests that the LMT sector in catching ups does not see any stability in its technological supporting tools and hence that the LMT sector in catching up economies is mainly interacting and integrating high technology products that are perceived to be dynamic. This supports the findings of Chen (2009) when studying the Taiwanese Tool industry, stressed the importance of suppliers for the LMT industry, in catching up economies (Taiwan). Accordingly, this catching up process could be achieved not only by the formal means of acquiring knowledge, in addition informal means play a pivotal role for countries in a catching up position. The same is not true for leading economies, where that stability is highly perceived as important across the economy. This therefore suggests, that catching up economies are going through a renewal phase and hence perceive opportunities from a different perspective by integrating high tech products to their stable technological arsenal.

Turning now to the factors that influence innovation, we find that a strong difference between the first three characteristics and the rest of the category. Factors, 10, 11, and 12 are concerned with regulatory approvals as means to a better commercialization cycle, protection from imitation, and intellectual property protection to capture value from innovation, respectively. For these three factors, catching up economies are completely populated with ones. This demonstrates the importance of such measures to capture value from innovation in these countries. The interesting result is the LMT in leading economies is losing ground with respect to such activities. This result both supports Mendonca (2009) and contradicts his inference regarding Robertson and Patel (2007). Mendonca, following the argument of Robertson and Patel (2007), suggested that developed countries excelling in HT, will certainly develop higher performance in lower techs, since both HT and LMT are mutually dependent. Our results suggest that the above argument is valid for catching up economies, but does not match our result for leading economies. However, Mendonca, forecasted this sustainable trajectory, highlighting that especially low tech industries are an important opportunity for countries lacking a high tech sector. From here, we can deduce the significant importance of LMT to the catching up process. This phenomenon of LMT losing grounds to HT in leading economies matches the findings of Lichtenthaler (2009) who compared patent portfolio analysis between LMT and HT on the European continent. His results suggest that patents’ aggressiveness in LMT is limited and that technological diversification has a negative effect on LMT firms, as well as a low patent quality.

In terms of resource inflows and growth, we find the following results. Government allocated resources (characteristic 20) are important in the case of HT and LMT in leading economies, however both ceased to consider this factor as important. This is not the case for the LMT in catching up economies. From an evolutionary perspective we can thus assert that while governments played a key role into building sectors in leading economies, in catching up economies, the focus is on LMT sectors. This governmental support is evident in the recent Taiwanese innovation survey focused on the LMT sector and analyzed by Tsai and Wang (2009). They found that the Taiwanese government is encouraging public research institutes to increase their research capacity to boost LMT competitiveness. Moreover, the Taiwanese government is putting pressures on universities to increase collaboration with LMT firms, by means of funding, grants and establishing state owned research centres (Lee and Wang, 2003). Lichtenthaler (2009) suggests increasing the governmental role in leading economies with respect to LMT sector to increase patent quality: a mandatory element to increase the performance of firms in the LMT sector (Ernst, 2001;Shane, 2001). This highlights that promoting such sectors is a priority for the catching up process, especially in the LMT.

The ease of start up funds (characteristic 21) seems to be dominant in leading economies compared to catching ups. However, for LMT in catching up economies, both factors (20 and 21) are mutually exclusive, in terms of 0s and 1s, implying that when governmental support dropped, the ease of start up funds emerged for LMT in catching up countries, probably through foreign direct investments (FDI) trying to capitalize from sectoral growth. These results support Gerchenkron's (1962) view, that financial institutions and governments play a key role in the catching-up process (Shin, 1996; Wade, 1990). Moreover, the above evidence proves that LMT activities are shifting from industrialized to newly industrialized countries as Robertson *et al.* (2009) state.

Factor 22, explaining sales growth compared to other sectors is also worth examining. On the one hand, HT in leading economies and LMT in catching ups are entirely populated with 1s. On the other hand, the LMT in leading countries and HT in catching ups are entirely populated with 0s. This hints towards national directives with respect to sectors, i.e. leading economies are focusing on HT, while catching ups are focusing on LMT. While the race might seem balanced, factor 23, explaining the sales in recently opened niche growth, demonstrates that catching ups start to put extra focus on HT as well. This is not true for leading economies that seem to have given up on LMT to the benefit HT, leaving LMT to catching ups.

Finally, our results on strategy and competition concentrate on factors 24-26 and 29. The importance of these characteristics reinforce our previous findings, with an entire population of 0s for LMT in leading economies, and a complete population of 1s in catching up economies for both sectors. The perception of technological change (characteristic 24), entry with breakthrough innovations (characteristic 25), technological frontier advancement (characteristic 26) and turbulence of sectors (characteristic 29) are perceived as very important by both sectors in catching ups, and by HT in leading economies. Those findings support Heindenreich (2009, p. 483) who states that “LMT industries are shrinking in Western Europe, and companies in these industries are relocating to Eastern Europe”. Radical/breakthrough innovation sharpens the ability to internally transform the LMT sector, if this radical new knowledge is properly absorbed (Freddi, 2009). This could be one argument supporting the rapid transformation of LMT in catching up economies. Furthermore, entry with breakthrough innovations, which is dominant for catching up economies, is generally found to be associated with closer bonds with university and research institutes (Tsai and Wang, 2009); a strategy that has been implemented by the Taiwanese government in the 1970s, establishing the Mechanical Industrial Research Laboratories (MIRL) and the Industrial Technology Research Institute (ITRI) (Chen, 2009).

5.8 Conclusion and Future Research Work

Our analysis shows that while on theoretical grounds, Universal Darwinism still has its critics (Khalil, 2009, this should not refrain from using evolutionary biology methodology to classify firms, sectors or economies. This paper demonstrates that such methodologies, offer a reasonable framework to explain evolution, on both sectoral and national systems of innovation. The methodology used enabled us to explore a stepwise evolution of best practices environments. In addition, it enabled us to further classify firms. Such an evolutionary view enhanced our understanding of the evolutionary process that might have occurred. Furthermore, it sharpened the comparative approach to understand both classification and evolution of firms.

For a proper conceptualization of this research work we should separate for a while between the theoretical framework and the methodology used. The methodology used, parsimony is generally used to validate Darwinian evolution due to its philosophical idea that matches to a great extent the Darwinian one. That is, characteristics evolving in a minimum number of evolutionary steps. This shortest path represents the selection process that makes the most adequate characteristics survive the various environmental stresses.

The theory however needs to be closely examined. The Neo Darwinian track supports the ideology that various minor changes occurring over a substantial period of time create a variety of distinct species, similar to the Darwinian approach. Species\cultural meme survival is based on the extent by which these modified characteristics enable the entity to get selected and survive. On the technological level, it is generally thought that if we consider the technology as a unit of analysis, the technology selection, and variation extends over the period of the technology development only, by constantly improving it. In that view, the technology itself, including its introduction and incremental innovations, is limited by the scope of the technology introduction until its maturity and declining lifespan. While this view is still debated by epistemologists, economists and technologists, the Lamarckian approach is still highly plausible.

However, if technology is seen as a set of practices, the Darwinian track becomes sufficient. It is not an exaggeration if one imagines that a current practice is a derivation from a previous one. Moreover, best practices generally can surpass firms’ lifetime until they become dominant in a certain sector or economy. Therefore, Technology, Management and Technology management could be abstracted into technical or managerial practices. Hence, the idea of Universal Darwinism can accurately represent the evolution of a sector or economy from a practices perspective. On speciation, it is logical to think that practices used by the same multinational differ according to geographic location. Such a form of adaptation is subject to the various socio-economic and cultural environmental stresses. Furthermore, the diffusion of practices that is witnessed in the case of multinationals could also diffuse, mutate, vary, adapt and get selected by educational and academic institutions.

This kind of speciation due to geographic locations has witnessed the diffusion of the various civilization practices since the civilization of ancient Egypt, and its effect on the various other civilizations emerging within the same Mediterranean continent. This argument is also appropriate for the emergence of the current western civilization that was ignited by the first industrial revolution: a revolution that gave rise to three consecutive ones, with various technologies such as communication and transportation, facilitating the acceleration of industrial development through a short time span. Therefore, if one looks to the current economic scene nowadays, through an evolutionary lens, one can see the traces of ancient core practices that probably changed their form but maintained their essence. For instance, internal knowledge development is a new form of the predominant culture, in ancient times to maintain knowledge for knowledge holders aiming to differentiate themselves, on the account of collaboration. This practice emanating from knowledge secrecy, since ancient Egyptian monks, and the guild dominant culture till its destruction by Adam Smith and the division of labor is an example of how practices can change across time, and geography.

The application of the presented methodology, supported by the proper theoretical perspective with historical data enables us to further analyze history, carefully examine substantial practices pitfalls to create a better future for generations to come.

5.9 References

Audretsch, D. B. (1996) Innovation and Industry Evolution, MIT Press, Cambridge, MA

Breschi, S., Malerba, F., Orsenigo, L. (2000) Technological regimes and Schumpeterian patterns of innovation, Economic Journal, 110, 388-410

Bruland, K., Mowery, D.C. (2005) Innovation through time in In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford.

Cesaroni, F., Gambardella, A., Garcia-Fontes, W., Mariani, M. (2004) The chemical sectoral system: firms, markets, institutions and the processes of knowledge creation and diffusion, In Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Chen, L. (2009) 'Learning through informal local and global linkages: the case of Taiwan's machine tool industry', Research Policy, Vol. 38, 527–535.

Christensen, C., Rosenbloom. R. (1995) Explaining the attacker advantage, Research Policy, 23, 2, 237-257

Constant, E. (2000) Recursive practice and the evolution of technological knowledge (Ch 16), in Technological innovation as an evolutionary process, Cambridge University Press

Constant, E. (2000) The evolution of war and technology (Ch 20), in Technological innovation as an evolutionary process, Cambridge University Press

Cordes, C. (2005) Long-Term tendencies in technological creativity-a preference- based approach, Journal of Evolutionary Economics, 15: 149-168

Cordes, C. (2006) Darwinism in Economics: from analogy to continuity, Journal of Evolutionary Economics, 16: 529-541

David, P. (2000), Path dependence and varieties of learning in the evolution of technological practice (Ch 10), in Technological innovation as an evolutionary process, Cambridge University Press

Dawkins, R. (1976) The Selfish Gene, Oxford University Press

Diamond, J. (1997) Guns, Germs and Steel: The fates of human societies, London: Jonathan Cape

Dosi, G. (1997) Opportunities, incentives, and the collective patterns of technological change, Economic Journal, 107, 1,530-1,547

Eck, R.V., Dayhoff, M.O. (1966) Atlas of Protein Sequence and structure 1966. National Biomedical Research Foundation, Silver Spring, Maryland.

Edquist, C. (2004) The fixed Internet and mobile telecommunications sectoral system of innovation: equipment production, access provision and content provision, in Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Edwards, A. W. F., Cavalli-Sforza, L.L. (1963) The reconstruction of evolution. Annals of Human Genetics 27: 105-106

Ernst, H., (2001) Patent applications and subsequent changes of performance: evidence from time-series cross-section analyses on the firm level. Research Policy30, 143–157.

Farris, J.S (1983) The logical basis of phylogenetic analysis. Pp.P.7-36 in Advances in Cladistics, Volume 2. Proceedings of the second meeting of the Willi Hennig Society, ed. N.H. Platnick and V.A. Funk. Columbia University Press, New York

Fagerberg, J., Godinho, M. (2005) Innovation and catching-up. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp.p. 514-542

Felsenstein, J. (2004) Inferring Phylogenies. Sinauer

Fleck, James (2000) Artefact-Activity: the co-evolution of artifacts, knowledge and organization in technological innovation (Ch 18), in Technological innovation as an evolutionary process, Cambridge University Press

Freddi, D. (2009) The integration of old and new technological paradigms in low and medium tech sectors: the case of mechatronics, Research Policy, 38: 548-558

Gaffney, E. S. (1979) An introduction to the logic of phylogeny reconstruction. P. 79-111 in Phylogenetic Analysis and Paleontology, Ed. J. Cracraft and N. Eldredge. Columbia University Press, New York

Geroski, P. (1995) What do we know about entry? International Journal of Industrial Organization, 4, 421, 440

Gerschenkron, A. (1962) Economic Backwardness in Historical Perspective, Cambridge, Mass: Belknap Press.

Ghosal, V., Nair-Reichert, U. (2009) Investments in modernization, innovation and gains in productivity: evidence from firms in the global paper industry, Research Policy, Vol. 38, pp.p.536–547.

Henderson, R., Clark, K. (1990) Architectural Innovation, Administrative Science Quarterly, 35, 9-30

Griffiths, P., Gray, R.D (1994) Developmental systems and evolutionary explanations. Journal of Philosophy 91: 277-304

Grimpe, C., Sofka, W. (2009) Search patterns and absorptive capacity: low- and high-technology sectors in European countries, Research Policy, Vol. 38, p.495–506.

Heidenreich, M. (2009) Innovation patterns and location of European low- and medium technology industries, Research Policy, Vol. 38, pp.p.483–494.

Hendy, M.D., Penny, D. (1982) Branch and Bound algorithms to determine minimum evolutionary trees. Mathematical Biosciences 60: 133-142

Hodgson, G.M. (2002) Darwinism in economics: from analogy to ontology. Journal of Evolutionary Economics 12: 259-281

Hull, D. L. (1988) Science as a Process: An Evolutionary Account of the Social and Conceptual Development of Science Chicago: University of Chicago Press; extract in Darwin: A Norton Critical Edition, 3rd edition, ed. Philip Appleman (2001), pp. 361-363.

Huson, D., Richter, D., Rausch, C., Dezulian, T., Franz, M., Rupp, R. (2007) Dendroscope*: An interactive viewer for large phylogenetic trees,* BMC Bioinformatics. Nov 22;8(1):460

Jablonka, E., Ziman, J. (2000) Biological Evolution: processes and phenomena (Ch2), in Technological innovation as an evolutionary process, Cambridge University Press

Jablonka, E. (2000) Lamarckian inheritance systems in biology: a source of metaphors and models in technological evolution (Ch 3), in Technological innovation as an evolutionary process, Cambridge University Press

Jovanovich, B., and G. M. MacDonald (1994) The life cycle of a competitive industry, Journal of Political Economy, 102, 2, 322-347

Khalil, E. (2009) Natural Selection and rational decision: two concepts of optimization, Journal of Evolutionary Economics 19- 417-435

Kluge, A. G., Farris, J.S. (1969) Quantitative Phyletics and the evolution of anurans. Systemcatic Zoology 18: 1-32

Kluge, A.G. (1997) Testability and the refutation and corroboration of cladistics hypotheses. Cladistics 13: 81-96

Kubler, G. (1982) The Shape of Time. Reconsidered. Perspecta, Vol. 19, pp.p. 112-121. Published by: The MIT Press on behalf of Perspecta.

Lee, J.S., Wang, J.C. (2003) Public policies for the promotion of an innovation-driven economy in Taiwan, International Journal of Entrepreneurship and Innovation Management 3, 227–248.

Lichtenthaler, U. (2009) The role of corporate technology strategy and patent portfolios in Low-Medium and High Tech firms, Research Policy, 38: 559-569

Macfarlane, A., Harrison, S. (2000) Technological Evolution and involution; a preliminary comparison of Europe and Japan (Ch 7), in Technological innovation as an evolutionary process, Cambridge University Press

Malerba, F., Orsenigo, L. (1999) Technological Entry, Exit, and survival: an empirical analysis of patent data, Research Policy, 28, 6, 643-660

Malerba, F. (2004) Sectoral Systems of innovation: concepts, issues, and analysis of six major sectors in Europe: Cambridge University Press

Malerba, F. (2005) Sectoral Systems , How and why innovation differs across sectors, in In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp.p. 514-542

McKelvey, M., Orsenigo, L., Pammolli ,F. (2004) Pharmaceuticals analyzed through the lens of a sectoral innovation systems in Sectoral Systems of Innovation, Concepts, issues and anlyses of six major sectors in Europe, Cambridge University Press

Maynard Smith, J. (1986) The problems of biology, Oxford University Press

Mendonca, S. (2009) Brave old world: Accounting for high tech knowledge in low tech industries, Research Policy, 38: 470-482

MetCalfe, S. (1998) Evolutionary Economics and creative destruction, Routledge, London

Mowery, D. C., Nelson R. R. (1999) Sources of industrial leadership: studies of seven industries, Cambridge University Press, Cambridge

Nelson R. R., Winter, S.G. (1982) An Evolutionary Theory of economic change, Harvard University Press, Cambridge MA

Nelson, R. R. (1995) Recent evolutionary theorizing about economic change, Journal of Economic Literature, 33, 1, 48-90

Nelson, R. R., Rosenberg, N. (1993) Technical Innovation and national systems, in R. R. Nelson (ed.) National Innovation Systems: A Comparative Analysis, Oxford University Press, Oxford

North, DC (1981) Structure and Change in Economic history. Norton, New York

Pavitt, K. (1984) Sectoral Patterns of technical change: towards a taxonomy and a theory, Research Policy, 13: 343-73

Popper, K. R (1968) The logic of scientific discovery, 2nd ed. Harper and Row, New York

Robertson, P., Smith, K. and Von Tunzelmann, N.(2009) Innovation in low- and medium-technology industries, Research Policy, Vol. 38, pp.p.441–446.

Robertson, P., Patel, P. (2007) New wine in old bottles: technology diffusion in developed countries. Research Policy 36, 708–721.

Santamaria, L., Nieto, M. and Barge-Gil, A. (2009) Beyond formal R&D: Taking advantage of other sources of innovation in low- and medium-technology industries, Research Policy, Vol. 38, pp.p.507–517.

Shane, S. (2001) Technology regimes and new firm formation. Management Science, 47, 1173–1190.

Shin, J. (1996) *The Economics of the Latecomers: Catching-up, Technology Transfer and Institutions in Germany, Japan and South Korea*, London: Routledge.

Stankiewicz, R. (2000) The concept of ‘design space’ (Ch 17), in Technological innovation as an evolutionary process, Cambridge University Press

SteinMueller , W. E. (2004) The European software sectoral system of innovation in Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Sutton, J. (1991) Sunk costs and Market structure, Cambridge, Mass: MIT press

Sutton, J. (1998) Technology and Market structure, Cambridge, Mass: MIT press

Tsai, K. and Wang, J. (2009) External technology sourcing and innovation performance in LMT sectors: an analysis based on the Taiwanese technological innovation survey, Research Policy, Vol. 38, pp.p.518–525.

Tushman, M., Anderson, P. (1986)Technological Discontinuities and organizational environments, Administrative Science Quarterly, 31, 3, 439, 465

Utterback, J. (1994) Mastering the dynamics of innovation, Harvard Business School Press, London

Von Hippel (1988) The sources of innovation (Oxford: Oxford University Press)

Von Tonzelmann, N., Acha ,V. (2005) Innovation in "Low-Tech" industries, Oxford Handbook of Innovation

Wade, R. (1990) Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization, Princeton: Princeton University Press.

Weber M (1993) The protestant ethic and the spirit of capitalism, Routledge London

Wengel, J., Shapira, P. (2004) Machine Tools: the remarking of a traditional sectoral innovation system in Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Wiley, E.O. (1981) Phylogenetics. The theory and practice of phylogenetic systematics. John Wiley and Sons, New York.

Ziman, J. (2000) Selectionism and complexity (Ch4), in Technological innovation as an evolutionary process, Cambridge University Press

Ziman, J. (2000) Evolutionary models for technological change, in Technological Innovation as an Evolutionary Process (Ch1), in Technological innovation as an evolutionary process, Cambridge University Press

Chapitre 6 GENERAL DISCUSSION

This research work aims to comparatively analyze LMT and HT, in leading and catching up economies. In order to reach the research objective, the LMT and HT sectors are first comparatively analyzed. Second, an additional country dimension is inserted that consists of leading versus catching up economies, with respect to the same set of variables. The two previous approaches were later tested using a phylogenetic tree in order to classify sectors and economies, and analyze characteristics evolution historically. In the introduction of this thesis, we identified the following three major research hypotheses, the third being rather exploratory, it aims to analyze Systems of Innovations (SI), National and Sectoral, from an evolutionary perspective:

H1: The HT sector has matured and we are currently witnessing a renewal and transformation phase, following the trajectory of the electronics sector (Robertson et al., 2009).

H2: The innovation strategic context for LMT in leading economies will be as advanced as its HT sector (Robertson and Patel, 2007; Mendonca, 2009). This level should be similar as well in Catching up economies, but with a lesser magnitude then in leading economies.

H3: An evolutionary approach using phylogenetic trees is appropriate for the classification of SIs and for the reconstruction of history from an evolutionary perspective.

Let us take each of these hypotheses in turn and state the main conclusion from each chapter.

First hypothesis H1

The HT sector has matured and we are currently witnessing a renewal and transformation phase, following the trajectory of the electronics sector (Robertson et al., 2009).

Results presented in chapter 2 are implying major strategic shifts and are pointing towards a renewal process in both sectors. Firms in HT, while focusing on product and breakthrough innovation that are fundamental to differentiation strategies are also occupied with large scale operations to minimize cost. This new strategic shift combining a mix of differentiation and cost focus is one of the major strategic directives that HT firms are currently following after the various industrial, and financial economic systems shakeouts following the Internet bubble burst in 2001. Furthermore, LMT firms, characterized with process innovation and cost based strategies, are bringing new innovations to market and are aiming to differentiate their products to avoid severe market cost competition. This product innovation is coupled with the traditional process innovations in the LMT to further support their differentiation strategies. One example of such strategies is to utilize high tech products such as ICT products to enhance the manufacturing process.

Due to their coherent R&D internal structures, their distinguished ability to produce GPT, and externally active behavior, firms in the HT sector are characterized with an extremely efficient absorptive capacity mechanism, if compared to LMT. However this absorptive capacity is better geared towards absorbing technical knowledge than predicting market moves. For instance this is represented by a higher dominance of HT firms, when compared to LMT firms, in the level of collaboration with universities and production of explicit scientific knowledge

Despite the high dominance of the linear model of innovation, HT firms are efficiently utilizing the open model of innovation. For instance, it is seen that HT firms still dominate knowledge production by interaction between firms. This is probably due to the HT firms' capacity to invest in appropriating their knowledge, and minimizing the risks related to collaboration.

HT and LMT firms are dependent on internal knowledge development. While this is natural for HT, our results imply that internal knowledge development in LMT did not weaken due to their dependency on external links to generate knowledge, which is commonly found in recent literature. In fact, it reinforces our understanding of the renewal of the LMT sector. Recent literature, like Tsai and Wang (2009), demonstrates that while focused on the externalization of knowledge acquisition for LMT, internal knowledge development is crucial to build firms' absorptive capacity. This finding supports the transformation hypothesis of the LMT sector. In this sector, firms are now more inclined to produce internal knowledge. One viable reason is for cost cutting purposes, or for minimization of the risks associated with externalizations, and increase differentiation.

While HT firms are serving complex customers, both sectors are closely aligned with their customers, but for different objectives however. On the one hand, HT firms align to better understand their client's needs and produce more innovative products. On the other hand, LMT firms are there to learn from customers and probably test the products that they are not able to test internally due to financial constraints.

In general, Governments allocated much more resources to support innovation in the HT sector. Furthermore, intellectual property protection is much more often used to appropriate innovations for HT firms. Regulatory approvals are used by both sectors equivalently. This finding is interesting, and contradicts our primary hypothesis for LMT. This contradiction supports recent findings of Mendonca (2009) that suggest that LMT firms are currently seeking to appropriate innovation and that regulatory forces play a key role in that sector. This is driven by the increased public awareness for health, security and safety for LMT products.

Hence, this research results supports the view of Robertson et al. (2009). Through our sample, both LMT and HT are going through a renewal and transformation phase. HT is transforming to reach more maturity, hinting towards a possible transformation like the case of the electronics sector. LMT is also getting transformed where on the product level, the utilization of GPT enabled it further differentiate it technologies and create new markets.

HT and LMT are going through sectoral renewal and transformation

Major research Hypothesis one (H1) is validated and accepted.

Second Hypothesis (H2)

The innovation strategic context for LMT in leading economies will be as advanced as its HT sector (Robertson and Patel, 2007; Mendonca, 2009). This level should be similar as well in Catching up economies, but with a lesser magnitude then in leading economies.

Internal R&D development is crucial to firms' survival, regardless its economical or sectoral boundaries. Knowledge generation through interaction in LMT is the most significant factor in favor of the catching economies. In general, previous studies showed that this kind of interaction is central to successful LMT, due to its cost efficiency, and the high quality of knowledge produced due to interactions between the various actors of the sectoral system, such as suppliers and clients. These interactions however are significant only in leading economies with respect to HT. As a result aside from internal R&D development, knowledge generation through firm's Interactions is central to the strategic innovation context of LMT in the catching up economies.

In addition to knowledge produced from firms' interactions, catching-up economies are putting a higher emphasis on knowledge produced from universities to benefit both sectors. While catching-up economies assign a diversified attention to both the LMT and HT, leading economies are focused on HT.

LMT in both economies rely more on a stable technological base. This is in contrast to HT that enjoys a more dynamic technological environment. Interestingly, catching-up economies, perceive knowledge generation to be more dependent on a stable technological base, compared to leading ones. This suggests that while the leaders are the innovators in both sectors, the catching-ups are the imitators.

Suppliers play a key role in HT located in leading economies, compared to LMT in their own economy (the leading one). This suggests that while the core products architectures are still produced in leading economies, probably the dependency on external suppliers increased specially with the general trend of product modularity. However, it is essential to mention that recent research has found that the Chinese automobile industry is recently shifting from the integral architecture to a quasi open modular architecture (Wang, 2008). Following that strategy, firms buy licenses or copies of generic parts and integrate the various components depending on the end product. This result suggests that firms in leading economies produce modular products, and then outsource components to catching up economies.

Furthermore, catching-up economies rely more on process innovation, especially in LMT that seems to be a core sector in these economies. The complexity of demand in leading economies surpasses that of the catching up economies. This probably explains that leading economies, while focusing on local markets, definitely try to penetrate foreign markets. Moreover, firms in leading economies face an even more complex demand that is satisfied by increasing products modularity.

What is even more interesting is that innovative start-ups, in catching up economies, enjoy a higher level of accessibility of funds to grow their business. This result is consistent in both the HT and LMT. This shows a focus on that sector in catching up economies. This supports the Gerschenkronian view that successful catching-ups depended more on their internal ability to enhance their institutional role to invest properly in education, innovation and R&D (Fagerberg & Godinho, 2005).

The important role of institutions, supporting Gerschenkronian's view, is clear in our analysis. Catching-ups do not only focus on education, in fact the regulatory framework in which catching-ups institutions played a key role is evident. This importance is obvious in the case of HT in leading economies. More importantly, this role is paralleled by a similar role in catching ups with respect to LMT. On the one hand, leading economies protect their HT investments by developing the appropriate regulatory policies. On the other hand, catching-ups are reinforcing the role of institutions especially in the case of LMT, as a means to catch-up. This result is logical, if the economic and technological perspectives of LMT are investigated. For instance, LMT firms in catching-ups, that generally are expert with export, should give key attention to regulatory approvals through their institutions in order to protect their investments. In the same vein, since catching-ups cannot afford much knowledge dissipation, intellectual property protection is mandatory to properly utilize innovations and protect their R&D investments. This institutional setup is supported by governments especially in the case of LMT in catching-ups.

Focused on LMT and export, catching up institutions play a key role in the expansion of global market shares. Firms achieve this by adhering to regulatory policies before the commercialization phase. In catching up economies, intellectual property protection institutions contribute to the efficient capture of value from innovations, and protect own production to avoid imitation. We could thus conclude that governments in catching-up economies are giving extra focus to LMT. Our results however suggest that governments for both economies are giving extra attention to HT.

Catching-ups perceive rapid sectoral growth in both sectors, more so in LMT. Leading economies do not seem to give the same attention to LMT compared to HT. While it is unmistakable that HT is the main engine for growth, its importance is decreasing with time. One explanation is that HT perhaps has reached the top of its S-shaped curve of technological innovation, and getting to be more of a stable and less turbulent sector. In contrast, LMT, which is considered the user of the HT products, now has a variety of technologies to deploy to enhance their process innovation, thus adding to the differentiation of their products portfolio. This suggests the renewal and transformation of such old, and slow growth perceived sector. Not only does technological differentiation, offered by the HT technologies support LMT firms, in addition this is coupled with a cost based strategy.

As a result of the above dynamics and growth elements, the LMT in both economies is witnessing advancement of its technological frontier. And hence, this sectoral transformation and redefinition is evident. However, this renewal and transformation places strong emphasis on LMT in catching-ups, which seems to have managed to attract the LMT sector within its national boundaries.

Those results prove the findings of Robertson and Patel (2007) and Mendonca (2009) in the case of catching up economies. However, our sample shows that leading economies giving extra attention to HT on the account of LMT.

Since HT and LMT are complementary, economies excelling in one of the sectors should excel in the other as well. This is true in Catching up Economies, not true however in the case of leading economies.

H2 is validated, accepted in the case of catching up economies, and is rejected in the case of leading economies.

Third hypothesis (H3)

An evolutionary approach using phylogenetic trees is appropriate for the classification of SIs and for the reconstruction of history from an evolutionary perspective.

From the phylogenetic analysis, we can see that the dominant characteristics are related to customers, and fulfilling their needs with the various complexities incorporated with such interactions. In addition, cost and competition strategies, technological superiority and the general understanding of external environmental dynamics are dominant characteristics. Therefore the above mentioned factors represent the most stable characteristics throughout the studied sample. These results suggest two important findings. On the sectoral level, results suggest that the differentiating element is not that obvious between HT and LMT with respect to various factors, as previously found by Malerba (2004). Hence supporting the renewal and transformation hypothesis examined through the first and second objectives in this research work.

The interaction between firms that characterized most LMT (Santamaria *et al.*, 2009; Tsai and Wang, 2009) is dominant for HT as well. In addition, knowledge development from within the firm is dominant regardless the sector. This supports the argument that absorptive capacity of firms in HT and LMT firms is well developed in both but probably for different reasons. For instance, Grimpe and Sofka (2009) suggested that LMT firms' absorptive capacity is focused on market inputs, while for HT firms it is focused on deep technological knowledge and expertise. Furthermore, while it is predominantly thought that LMT firms are more cost driven (Von Tunzelmann and Acha, 2005), HT firms seem to be following a recent cost focus as well. Process innovation, which is dominantly thought to be a main characteristic of LMT firms (Ghosal and Nair-Reichert, 2009; Santamaria *et al.*, 2009; Heidenreich, 2009), is seen to be a dominant characteristic of HT firms as well. On the national level, research findings demonstrate the effect of globalization on business practices, with respect to the above characteristics. For instance, the increasing complexity in consumer tastes, and its international expansion (Mendonca, 2009) would put pressures on firms to perform in a certain unified way. The above results suggest a renewal and transformation of the two studied sectors regardless the national system of innovation within which they reside.

When analyzing knowledge production mechanisms, it was found that this factor has dropped in importance in LMT in leading economies, while the opposite happened in catching up economies for both sectors; this supports the findings of Fagerberg and Godinho (2005) and Tsai and Wang (2009). Furthermore, in catching up economies, the perception of firms to be relying on a stable technological base is predominantly nullified, especially in the LMT sector. This suggests that the LMT sector in catching ups does not see any stability in its technological supporting tools and hence that the LMT sector in catching up economies is mainly interacting and integrating high technology products that are perceived to be dynamic. While this might seem to contradict the findings of chapter 3, in fact it shows that from an evolutionary perspective, the perception of less stability supports the recent innovative strategies firms in LMT catching up economies are pursuing.

This supports the findings of Chen (2009) who, when studying the Taiwanese Tool industry, stressed the importance of suppliers for the LMT industry, in catching up economies (Taiwan). Accordingly, this catching up process could be achieved not only by the formal means of acquiring knowledge; in addition informal means play a pivotal role for countries in a catching up position. The same is not true for leading economies, where that stability is highly perceived as important across the economy. This therefore suggests, that catching up economies are going through a renewal phase and hence perceive opportunities from a different perspective by integrating high tech products to their stable technological arsenal.

When studying the factors that influence innovation, we focus on the three main differentiating factors concerned with regulatory approvals as means to a better commercialization cycle, protection from imitation, and intellectual property protection to capture value from innovation, respectively. It is found that LMT in leading economies is losing ground with respect to such activities, while highlighting the significant importance of LMT to the catching up process. This phenomenon of LMT losing grounds to HT in leading economies matches the findings of Lichtenthaler (2009) who compared patent portfolio analysis between LMT and HT on the European continent. His results suggest that patents' aggressiveness in LMT is limited and that technological diversification affected European LMT firms negatively.

In terms of resource inflows and growth, we find that governments played a key role into building HT sectors in leading economies; however, in catching up economies, the focus is on LMT sectors. This governmental support is evident in the recent Taiwanese innovation survey focused on the LMT sector and analyzed by Tsai and Wang (2009). They found that the Taiwanese government is encouraging public research institutes to increase their research capacity to boost LMT competitiveness. Moreover, the Taiwanese government is putting pressures on universities to increase collaboration with LMT firms, by means of funding, grants and establishing state owned research centres (Lee and Wang, 2003). Lichtenthaler (2009) suggests increasing the governmental role in leading economies with respect to LMT sector to increase patent quality: a mandatory element to increase the performance of firms in the LMT sector (Ernst, 2001; Shane, 2001). This highlights that promoting such sectors is a priority for the catching up process, especially in the LMT.

The ease of start up funds is dominant in leading economies compared to catching ups. However, for LMT in catching up economies, governmental support and the ease of start up funds are mutually exclusive. This hints towards a fine coordination between government and the various agents on the national system of innovation.

When examining sales growth results show that leading economies are focusing on HT, while catching ups are focusing on LMT. While the race might seem balanced sales in recently opened niche growth, demonstrates that catching ups start to put extra focus on HT as well. This is not true for leading economies that seem to have given up on LMT to the benefit HT, leaving LMT to catching ups.

These findings correctly verified the findings of H1 and H2, hence H3 is validated, and accepted

The feasibility of a phylogenetic tree approach to classify firms within systems of innovation (HT, LMT, Leading and Catching ups) is verifiable and enabled the inference of the evolution of the best practices within these systems

CONCLUSION AND RECOMMENDATIONS

This research overall finding suggest that HT and LMT are going through a renewal and transformation phase. One of the main drivers of the renewal and transformation process is emergence of catching up economies that give focus to all industrial sectors, however, with a stronger emphasis on LMT. This result has been verified statistically and using phylogenetic trees analysis.

On the theoretical level, one major implication of this transformation and renewal process is the OECD sectoral classification itself. This new transformation implies an expected increase of investment in the LMT sectors that are currently witnessing support to enhance their firms' internal R&D. This phenomenon will most likely change the definition of OECD of LMT. While generally, the OECD classifies high tech firms to be investing more than 5% of their turn over on R&D, an increase in that direction might lead to a shift from some of the medium-high tech firms to the high tech zone. In the same vein, with the current economic crisis, the cost awareness regime that HT firms are increasingly deploying, together with the tightening of internal R&D investment, the classically defined high tech firms that will cease to invest in R&D will probably slip to more of a medium tech industry, according to the OECD definition. If a leader-follower process emerged, together with a consistent flow of high tech firms reducing R&D investment, the whole sector might transform, and join a lower classification. This suggests the redefinition of the OECD to the sectors undergoing the renewal and transformation processes. Otherwise, we might witness high tech firms slipping into lower categories of sectoral classification.

Since some of the witnessed innovation dynamics were based on national systems of innovation, such a classification of sector should take into consideration variations occurring on the national levels. Hence, this research work calls for a renewed international industrial policy that takes into consideration the various changes in the global markets taking the various OECD economic survey reports into consideration.

In practice, the various agents presented in the paper will be affected by this renewal and transformation process. Universities that probably depended more classically on high tech firms for contracts might need to diversify their collaboration agreements to include low and medium tech firms. This necessitates that firms in LMT, which increasingly depend on internal research, increase their collaboration with universities so that it can provide the same role it does with the HT industry. High tech firms that are seeking to be more cost aware, however are least likely to change their innovation mix to increase their dependency on universities than internally, due to their cost minimization process. Furthermore, Governments that have once encouraged HT, should be more aware that HT might not be able to sustain and provide the same growth levels it once provided, and hence the encouragement of the LMT might be more helpful in order to increase economic growth, and decrease unemployment rates.

Furthermore adding to the above factors with respect the two sectors, our general results suggest that catching up countries are strategizing for this sectoral evolution, renewal and transformation process, for both sectors however with a stronger emphasis on the LMT. This international policy aiming to master LMT by catching up countries on the account of the leading ones, should trigger the question whether LMT is still of strategic importance to leading countries. If this proves to be the case, much attention should be given to LMT with respect to the various economic agents that constitute the national system of innovation of leading economies. Such attention could be given by establishing proper bonds between LMT and HT sectors to better enhance its innovative capacity. Such an attention could include more governmental fund, and university collaboration to reenter this sectoral race.

This research work presented the phylogenetic tree approach to verify the first two research hypotheses, classify sectors and economies, as well as to analyze the evolution of sectoral and national systems of innovation. Fitting the evolution of sectors through the MINE survey questionnaire was established by hypothesizing that the questionnaire was actually asking questions about best practices. These best practices are subject the various evolutionary processes such as variation and environmental /natural selection. These two steps are the basics of the Darwinian evolution, or Universal Darwinism in case of using cultural evolution terminology. The basic priori when using the methodology for classification is that perceptions of agents in the same sector, or same economy are more or less the same. Therefore, the methodology will enable differentiate between sectors or economies. However, the methodology offers more than classification. In other words, the methodology used, classifies based on common shared derived characteristics. Meaning that the more these firms' perceptions are similar the more they will be grouped on closer branches, and to a common node. From here, tracking back the changes occurring on the tree was feasible.

The methodology used enabled us to explore a stepwise evolution of best practices environments. In addition, it enabled us to further classify firms. Such an evolutionary view enhanced our understanding of the evolutionary process that might have occurred. Furthermore, it sharpened the comparative approach to understand both classification and evolution of firms. Phylogenetic tree tools could serve the various economic entities to further classify sectors, and dealing with huge amounts of data. In this research work, data used was only cross sectional.

Future research work, besides adding other sections of the MINE survey, will also add a historical dimension by bringing historical data to further support the findings of the analysis. Furthermore, such a methodology when added to the classical multivariate analysis tools offers a rich analytical environment for analysts aiming to classify, or understand the evolution of the data filling our complex economic space.

REFERENCES

Abramovitz, M. (1986) "Catching Up, Forging Ahead, and Falling Behind" Journal of Economic History 46: 386-406

Abramovitz, M. (1994) "The Origins of the Postwar Catch-Up and Convergence Boom" in J. Fagerberg, B. Verspagen and N. Von Tunzelmann (eds), The Dynamics of Technology, Trade and Growth, Aldershot: Edward Elgar, 21-52

Aiginger, K. (2007) Industrial Policy: A Dying Breed or A Re-emerging Phoenix. Journal of Industry, Competition and Trade. Hingham:Vol. 7, Iss. 3-4; pg. 297, 27 pgs

Amir, R. , Evstigneeve, I., Wooders, J. (2003) Noncooperative versus Cooperative R&D with Endogenous Spillover Rates, Games and Economic behavior, 42, 183-207

Arrow, K. J. (1962) The economics of learning by doing. Review of Economic studies

Audretsch, D. B. (1996) Innovation and Industry Evolution, MIT Press, Cambridge, MA

Bellone, F. (2008) The role of domestic savings in outward-oriented growth strategies. Journal of Evolutionary Economics. Heidelberg: Vol. 18, Iss. 2; pg. 183, 17 pgs

Berg, M. (1998) Product Innovation in Core Consumer Industries in Eighteenth Century Britain, in M. Berg and K. Bruland (eds.), Technological Revolutions in Europe: Historical Perspectives, Cheltenham: Edward Elgar, 138-58

Braudel, F. (1984) The perspective of the World, Berkeley: Univeristy of California Press

Breschi, S., Malerba, F. (1997) "Sectoral Innovation Systems: Technological Regimes, Schumpetarian Dynamics, and Spatial Boundaries" In Edquist (1997).

Breschi, S., Malerba, F., Orsenigo, L. (2000) Technological regimes and Schumpeterian patterns of innovation, Economic Journal, 110, 388-410

Bruland, K., Mowery, D. (2005) Innovation through time. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), The Oxford Handbook of Innovation. Oxford University Press, Oxford, pp. 349-379

Burns, J. (2000) Learning about technology in society: developing liberating literacy (Ch 21), in Technological innovation as an evolutionary process, Cambridge University Press

Campbell, D.T (1974) Evolutionary Epistemology. In the Philosophy of Karl Popper, Edited by Schilpp, P.A. (La Salle IL: Open Court), pp 413-63

Carlsson, B. (Ed.) (1995) Technological systems and Economic Performance: the case of Factory automation. Kluwer Academic Publishers, Boston

Cavallaro, E., Mulino, M. (2008) Vertical Innovation and Catching-Up: Implications of EU Integration for CEECs-5. International Advances in Economic Research. Edwardsville Vol. 14, Iss. 3; pg. 265, 15 pgs

Cesaroni, F., Gambardella, A., Garcia-Fontes, W., Mariani, M. (2004) The chemical sectoral system: firms, markets, institutions and the processes of knowledge creation and diffusion, In Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Chandler, A. (1962) Strategy and Structure: Chapters in the History of the American Industrial Enterprise. Cambridge, MA: MIT Press

Chen, L. (2009) 'Learning through informal local and global linkages: the case of Taiwan's machine tool industry', Research Policy, Vol. 38, 527-535.

Chesbrough, H. (2003) Open Innovation-The new Imperative for creating and profiting from technology. Harvard Business School Press, Boston

Christensen, C., Rosenbloom. R. (1995) Explaining the attacker advantage, Research Policy, 23, 2, 237-257

Cohen,W.M., Levinthal, D.A. (1990) Absorptive capacity: a new perspective of learning and innovation. Administrative Science Quarterly 35, 128-152.

Constant, E. (2000) Recursive practice and the evolution of technological knowledge (Ch 16), in Technological innovation as an evolutionary process, Cambridge University Press

Constant, E. (2000) The evolution of war and technology (Ch 20), in Technological innovation as an evolutionary process, Cambridge University Press

Cooke, P., Gomez Urgana, M., Etxebarria, G (1997) "Regional Systems of Innovation: Institutional and Organizational Dimensions" Research Policy 26:475-91

Cordes, C. (2005) Long-Term tendencies in technological creativity-a preference- based approach, Journal of Evolutionary Economics, 15: 149-168

Cordes, C. (2006) Darwinism in Economics: from analogy to continuity, Journal of Evolutionary Economics, 16: 529-541

David, P. (2000) Path dependence and varieties of learning in the evolution of technological practice (Ch 10), in Technological innovation as an evolutionary process, Cambridge University Press

Dawkins, R. (1976) The Selfish Gene (Oxford: Oxford University Press)

Diamond, J. (1997) Guns, Germs and Steel: The fates of human societies, London: Jonathan Cape

Dosi, G. (1997) Opportunities, incentives, and the collective patterns of technological change, Economic Journal, 107, 1,530-1,547

Eck, R.V., Dayhoff, M.O. (1966) Atlas of Protein Sequence and structure 1966. National Biomedical Research Foundation, Silver Spring, Maryland.

Edquist, C. (ed.) (1997) Systems of Innovation: Technologies, Institutions and Organizations, London: Printer

Edquist, C. (2004) The fixed Internet and mobile telecommunications sectoral system of innovation: equipment production, access provision and content provision, in Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Edquist, C. (2005) Systems of Innovation: Perspectives and Challenges. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), The Oxford Handbook of Innovation. Oxford University Press, Oxford, pp. 349-379

Edwards, A. W. F., Cavalli-Sforza, L.L. (1963) The reconstruction of evolution. Annals of Human Genetics 27: 105-106

Ernst, H., (2001) Patent applications and subsequent changes of performance: evidence from time-series cross-section analyses on the firm level. Research Policy30, 143-157.

Fagerberg, J. (2005) Innovation: a guide to the literature. In: Fagerberg, J., Mowery, D., Nelson, R. (Eds.), Oxford Handbook of Innovation. Oxford University Press, Oxford, pp. 1-26.

Fagerberg, J., Godinho, M. (2005) Innovation and catching-up. In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), The Oxford Handbook of Innovation. Oxford University Press, Oxford, pp. 514-542

Fairtlough, G. (2000) The organization of innovative enterprises (Ch 19), in Technological innovation as an evolutionary process, Cambridge University Press

Fan, P. (2006) Catching up through developing innovation capability: evidence from China's telecom-equipment industry. Technovation. Amsterdam: Vol. 26, Iss. 3; pg. 359

Farris, J.S (1983) The logical basis of phylogenetic analysis. Pp.P.7-36 in Advances in Cladistics, Volume 2. Proceedings of the second meeting of the Willi Hennig Society, ed. N.H. Platnick and V.A. Funk. Columbia University Press, New York

Felsenstein, J. (2004) Inferring Phylogenies. Sinauer

Fleck, J. (2000) Artefact-Activity: the co-evolution of artifacts, knowledge and organization in technological innovation (Ch 18), in Technological innovation as an evolutionary process, Cambridge University Press

Freddi, D. (2009) The integration of old and new technological paradigms in low and medium tech sectors: the case of mechatronics, Research Policy, 38: 548-558

Freeman, C. (1987) Technology Policy and Economic Performance: Lessons from Japan, London: Pinter.

Freeman, C., Louca, F. (2001) As Time Goes By: From the Industrial Revolutions to the Information Revolution, Oxford: Oxford University press

Freeman, C., Perez, C. (1988) "Structural Crises of Adjustment: Business Cycles and Investment Behavior." In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds), Technical Change and Economic Theory, London: Pinter, 36-66

Freeman, C., Soete, L. (1997) The Economics of Industrial Innovation, 3rd edn, London: Pinter

Gaffney, E. S. (1979) An introduction to the logic of phylogeny reconstruction. P. 79-111 in Phylogenetic Analysis and Paleontology, Ed. J. Cracraft and N. Eldredge. Columbia University Press, New York

Gardner Publication (2007) World machine tool output and consumption survey, http://www.gardnerweb.com/consump/survey.html.

Geroski, P. (1995) What do we know about entry? International Journal of Industrial Organization, 4, 421, 440

Gerschenkron, A. (1962) Economic Backwardness in Historical Perspective, Cambridge, Mass: Belknap Press.

Ghosal, V., Nair-Reichert, U. (2009) Investments in modernization, innovation and gains in productivity: evidence from firms in the global paper industry, Research Policy, Vol. 38, pp.p.536-547.

Grant, R.M. (1996) Toward a knowledge-based theory of the firm. Strategic Management Journal 17, 109-122.

Griffiths, P., Gray, R.D (1994) Developmental systems and evolutionary explanations. Journal of Philosophy 91: 277-304

Grimpe, C., Sofka, W. (2009) Search patterns and absorptive capacity: low- and high-technology sectors in European countries, Research Policy, Vol. 38, p.495-506.

Heidenreich, M. (2009) Innovation patterns and location of European low- and medium-technology industries. Research Policy 38 (2009) 483-494

Helpman, E. (ed.) (1998) General Purpose Technologies and Economic Growth, Cambridge, Mass: MIT Press

Henderson, R., Clark, K. (1990) Architectural Innovation, Administrative Science Quarterly, 35, 9-30

Hendy, M.D., Penny, D. (1982) Branch and Bound algorithms to determine minimum evolutionary trees. Mathematical Biosciences 60: 133-142

Hodgson, G.M. (2002) Darwinism in economics: from analogy to ontology. Journal of Evolutionary Economics 12: 259-281

Hsieh, C., Löfgren, H. (2009) Biopharmaceutical innovation and industrial developments in South Korea, Singapore and Taiwan. Australian Health Review. Sydney: Vol. 33, Iss. 2; pg. 245, 13 pgs

Hull, D. L. (1988) Science as a Process: An Evolutionary Account of the Social and Conceptual Development of Science Chicago: University of Chicago Press; extract in Darwin: A Norton Critical Edition, 3rd edition, ed. Philip Appleman (2001), pp. 361-363.

Huson, D., Richter, D., Rausch, C., Dezulian, T., Franz, M., Rupp, R. (2007) Dendroscope: An interactive viewer for large phylogenetic trees, BMC Bioinformatics. Nov 22;8(1):460

Jablonka, E. (2000) Lamarckian inheritance systems in biology: a source of metaphors and models in technological evolution (Ch 3), in Technological innovation as an evolutionary process, Cambridge University Press

Jablonka, E., Ziman, J. (2000) Biological Evolution: processes and phenomena (Ch2), in Technological innovation as an evolutionary process, Cambridge University Press

Jovanovich, B., MacDonald G.M. (1994) The life cycle of a competitive industry, Journal of Political Economy, 102, 2, 322-347

Katila, R., Ahuja, G. (2002) Something old, something new: a longitudinal study of search behavior and new product introduction. Academy of Management Journal 45 (6), 1183-1194

Katz, M. (1986) An Analysis of Cooperative Research and Development, The RAND Journal of Economics, vol. 17, No. 4 (winter)

Khalil, E. (2009) Natural Selection and rational decision: two concepts of optimization, Journal of Evolutionary Economics 19- 417-435

Kluge, A. G., Farris, J.S. (1969) Quantitative Phyletics and the evolution of anurans. Systemcatic Zoology 18: 1-32

Kluge, A.G. (1997) Testability and the refutation and corroboration of cladistics hypotheses. Cladistics 13: 81-96

Kodama, F. (1992) Technology fusion and the new R&D. Harvard Business Review 70 (4), 70-78.

Kubler, G. (1982) The Shape of Time. Reconsidered. Perspecta, Vol. 19, pp.p. 112-121. Published by: The MIT Press on behalf of Perspecta.

Landes, D. (1998) The wealth and Poverty of Nations, London: Little, Brown and Co.

Laursen, K., Salter, A. (2006) Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. Strategic Management Journal 27, 131-150.

Lee, J.S., Wang, J.C. (2003) Public policies for the promotion of an innovation-driven economy in Taiwan, International Journal of Entrepreneurship and Innovation Management 3, 227-248.

Li, J., Kozhikode, R. (2008) Knowledge management and innovation strategy: The challenge for latecomers in emerging economies. Asia Pacific Journal of Management. Singapore. Vol. 25, Iss. 3; pg. 429, 22 pgs

Lichtenthaler, U. (2009) The role of corporate technology strategy and patent portfolios in Low-Medium and High Tech firms, Research Policy, 38: 559-569

Liu, R.-J., Brookfield, J. (2000) Stars, rings and tiers: organizational networks and their dynamics in Taiwan's MT industry. Long Range Planning 33 (3), 322-348

Lundvall, B.,-A, Johnson, B. (1994) The learning economy. Journal of Industrial Studies 1(2), 23-41.

Lundvall, B.-A. (1988) Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: Dosi, G., Freeman, C., Nelson, R.,Silverberg, G., Soete, L. (Eds.), Technical Change and Economic Theory. Pinter Publishers, New York, pp. 347-369.

Lundvall, B.-A. (ed.) (1992) National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter.

Macfarlane, A., Harrison, S. (2000) Technological Evolution and involution; a preliminary comparison of Europe and Japan (Ch 7), in Technological innovation as an evolutionary process, Cambridge University Press

MacLeod, C. (1988) Inventing the Industrial Revolution: The English Patent System 1660-1800, Cambridge, Cambridge University Press

Malerba, F. (ed.) (2004) Sectoral Systems of Innovation: Concepts, Issues and Analyses of Six Major Sectors in Europe. Cambridge University Press, Cambridge.

Malerba, F. (2005) Sectoral Systems , How and why innovation differs across sectors, in In Fagerberg, J., Mowery, D.C., Nelson, R. R. (Eds), The Oxford Handbook of Innovation. Oxford University Press, Oxford, pp.p. 514-542

Malerba, F., Nelson, R., Orsenigo, L., Winter, S. (2001) Competition and industrial policies in a 'history friendly' model of the evolution of the computer industry. International Journal of Industrial Organization, 19(5), 635-664.

Malerba, F., Orsenigo, L. (1999) Technological Entry, Exit, and survival: an empirical analysis of patent data, Research Policy, 28, 6, 643-660

Malerba, F., Orsenigo, L. (2001) Towards a history friendly model of innovation, market structure and regulation in the dynamics of the pharmaceutical industry, The age of random screening. Paper presented at the CESPRI Working paper.

Maynard Smith, J. (1986) The problems of biology, Oxford University Press

Mazzoleni, R. (2008) Catching Up and Academic Institutions: A Comparative Study of Past National Experiences. The Journal of Development Studies. London: Vol. 44, Iss. 5; pg. 678

McKelvey, M., Orsenigo, L., Pammolli ,F. (2004) Pharmaceuticals analyzed through the lens of a sectoral innovation systems in Sectoral Systems of Innovation, Concepts, issues and anlyses of six major sectors in Europe, Cambridge University Press

Mendonca, S. (2009) Brave old world: Accounting for high tech knowledge in low tech industries, Research Policy, 38: 470-482

Meriküll, J. (2010) The Impact of Innovation on Employment: Firm- and Industry-Level Evidence from a Catching-Up Economy. Eastern European Economics. Armonk: Vol. 48, Iss. 2; pg. 25

MetCalfe, S. (1998) Evolutionary Economics and creative destruction, Routledge, London

Mokyr, J. (1990) The lever of Riches (New York NY: Oxford University Press)

Mokyr, J. (2000) Evolutionary Phenomena in technological change (Ch5), in Technological innovation as an evolutionary process, Cambridge University Press

Mowery, D. C., Nelson R. R. (1999) Sources of industrial leadership: studies of seven industries, Cambridge University Press, Cambridge

Nelson R. R., Winter, S.G. (1982) An Evolutionary Theory of economic change, Harvard University Press, Cambridge MA

Nelson, R. R. (ed.) (1993), National Systems of Innovation: A comparative Study, Oxford: Oxford University Press.

Nelson, R. R. (1995) Recent evolutionary theorizing about economic change, Journal of Economic Literature, 33, 1, 48-90

Nelson, R. (2000) Selection and selection processes in cultural evolution (Ch6),in Technological innovation as an evolutionary process, Cambridge University Press

Nelson, R. R., Rosenberg, N. (1993) Technical Innovation and national systems, in R. R. Nelson (ed.) National Innovation Systems: A Comparative Analysis, Oxford University Press, Oxford

Niosi, J. (2003) Alliances are not enough explaining rapid growth in biotechnology firms. Research policy 32 (2003) 737-750

Norma, V. (2005) Essays on university-industry collaboration, Ph.D. Dissertation, New School University, 175 pages; AAT 31

North, DC (1981) Structure and Change in Economic history. Norton, New York

OECD (1994) Science and Technology Policy: Review and Outlook. OECD, Paris.

OECD (2003) Science, Technology and Industry Scoreboard 2003 - Towards a Knowledge-based economy. OECD, Paris.

OECD Economic Surveys (2006) Upgrading Japan's innovation system to sustain economic growth. Paris: Iss. 13; pg. 127, 39 pgs

OECD Economic Surveys (2007) Challenges facing the Austrian economy Anonymous. Paris: Iss. 15; pg. 19, 24 pgs

OECD Economic Surveys (2010) Chapter 3: Need for speed: Boosting productivity growth by strengthening competition, entrepreneurship and innovation. Paris: Iss. 1; pg. 65, 37 pgs

Pacey, A. (1983)The culture of technology (Oxford: Blackwell)

Park, J. (1987) Dynamic Patent Races with Risky Choices, Management Science, Vol.33, No. 12 (Dec.,1987),pp.1563-1571

Pavitt, K. (1984) Sectoral patterns of technical change: towards a taxonomy and a theory. Research Policy 13, 343-373

Pomeranz, K.R. (2000) The Great Divergence: China, Europe and the Making of the Modern Work Economy, Princton: Princeton University Press.

Popper, K. R (1968) The logic of scientific discovery, 2nd ed. Harper and Row, New York

Reinganum, J. F. (1981) On The diffusion of New Technology: a Game Theoretic Approach, The Review of Economic Studies, Vol. 48, No. 3 (Jul.), pp. 395-405

Robertson, P., Patel, P. (2007) New wine in old bottles: technology diffusion in developed countries. Research Policy 36, 708-721.

Robertson, P., Smith, K. and Von Tunzelmann, N.(2009) Innovation in low- and medium-technology industries, Research Policy, Vol. 38, pp.p.441-446.

Santamaria, L., Nieto, M. and Barge-Gil, A. (2009) 'Beyond formal R&D: Taking advantage of other sources of innovation in low- and medium-technology industries', Research Policy, Vol. 38, pp.507-517.

Saxenian, A. (1994) Regional advantage: Culture and Competition in Silicon Valley and Route 128. Harvard University Press .Cambridge. MA.

Shane, S. (2001) Technology regimes and new firm formation. Management Science, 47, 1173-1190.

Shapiro, C. (1989) The Theory of Business Strategy, The RAND Journal of Economics, Vol. 20, No. 1 (Spring), pp. 125-137

Shin, J. (1996) The Economics of the Latecomers: Catching-up, Technology Transfer and Institutions in Germany, Japan and South Korea, London: Routledge.

Society of Manufacturing Engineering (2007) Still Ahead But for How Long? Manufacturing Engineering. (www.sme.org) Dearborn: Vol. 138, Iss. 4; pg. 30, 2 pgs

Stankiewicz, R. (2000) The concept of 'design space' (Ch 17), in Technological innovation as an evolutionary process, Cambridge University Press

SteinMueller , W. E. (2004) The European software sectoral system of innovation in Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Stewart, I. (2003) Does God Play Dice? The new mathematics of Chaos (Second Edition ed.): Blackwell Publishing.

Sullivan, R. (1990) The Revolution of Ideas: Widespread Patenting and Invention During the Industrial Revolution, Journal of Economic History 50(2): 340-62

Sutton, J. (1991) Sunk costs and Market structure, Cambridge, Mass: MIT press

Sutton, J. (1998) Technology and Market structure, Cambridge, Mass: MIT press

Tsai K., Wang J. (2009) External Technology sourcing and Innovation performance in LMT sectors: An analysis based on the Taiwanese Technological Innovation Survey. Research Policy 38, 470-482

Tu, C., Yang, S. (2008) National System of S&T Innovation: Dynamics of Manpower Building in a Catching-Up Economy Journal of Asia - Pacific Business. Binghamton: Vol. 9, Iss. 2; pg. 153

Tushman, M., Anderson, P. (1986)Technological Discontinuities and organizational environments, Administrative Science Quarterly, 31, 3, 439, 465

Utterback, J. (1994) Mastering the dynamics of innovation, Harvard Business School Press, London

Van Schaik, A., Van de Klundert, T (2010) Productivity Growth and the Labour Market. SSRN Working Paper Series. Rochester

Veblen, T. (1915) Imperial Germany and the Industrial Revolution, New York: Macmillan

Viardot, E. (2004) Successful marketing strategy for High-Tech firms, 3rd Ed. Artech House, Inc.

Vincenti, W. (2000) Real-world variation-selection in the evolution of technological form: historical examples (Ch 13),in Technological innovation as an evolutionary process, Cambridge University Press

Von Hippel (1988) The sources of innovation (Oxford: Oxford University Press)

Von Tunzelmann, N. and Acha, V. (2005) 'Innovation in 'low-tech' industries', in Fagerberg, J., Mowery, D.C. and Nelson, R.R. (Eds): The Oxford Handbook of Innovation, Oxford University Press, Oxford, pp.408-432.

Wade, R. (1990) Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization, Princeton: Princeton University Press.

Wallerstein, J. (1974) Capitalist Agriculture and the Origins of the Modern World Economy, New York: Academic Press.

Wang, H. (2008) Innovation in product architecture--A study of the Chinese automobile industry. Asia Pacific Journal of Management. Singapore: Vol. 25, Iss. 3; pg. 509, 27 pgs

Wang, J. (2007) From Technological Catch-Up to Innovation-based Economic Growth: South Korea and Taiwan Compared The Journal of Development Studies. London: Vol. 43, Iss. 6; pg. 1084

Weber M (1993) The protestant ethic and the spirit of capitalism, Routledge London

Wei, J., Malik, K., Shou, Y. (2005) A pattern of enhancing innovative knowledge capabilities: Case study of a Chinese telecom manufacturer. Technology Analysis & Strategic Management. Abingdon Vol. 17, Iss. 3; pg. 355

Wengel, J., Shapira, P. (2004) Machine Tools: the remarking of a traditional sectoral innovation system in Sectoral Systems of Innovation, Concepts, issues and analyses of six major sectors in Europe, Cambridge University Press

Wiley, E.O. (1981) Phylogenetics. The theory and practice of phylogenetic systematics. John Wiley and Sons, New York.

Xie, W., Zedtwitz, M. (2010) Main characteristics of world-first innovation in catching-up countries. Journal of Technology Management in China. Bradford:Vol. 5, Iss. 2; pg. 108

Zahra, S.A., Keil, T., Maula, M., (2005) New ventures' inward licensing: examining the moderating role of firm's competitive environment. Journal of Business Venturing 11, 189-219.

Ziman, J. (2000) Evolutionary models for technological change, in Technological Innovation as an Evolutionary Process (Ch1), in Technological innovation as an evolutionary process, Cambridge University Press

Ziman, J. (2000) Selectionism and complexity (Ch4), in Technological innovation as an evolutionary process, Cambridge University Press