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DINÂMICA DE SISTEMAS SETORIAIS DE INOVAÇÃO:
Um modelo de simulação aplicado no Setor Brasileiro de Software

Tese submetida ao Programa de Pós Graduação em Engenharia e Gestão do Conhecimento da Universidade Federal de Santa Catarina para a obtenção do Grau de Doutor em Engenharia e Gestão do Conhecimento
Orientador: Prof. Dr. Gregório J. Varvakis.
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Florianópolis
2012

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Uriona Maldonado, Mauricio
Dinâmica de Sistemas Setoriais de Inovação [tese] : Um modelo de simulação aplicado no Setor Brasileiro de Software / Mauricio Uriona Maldonado ; orientador, Gregório Varvakis ; co-orientador, Vinícius Kern. - Florianópolis, SC, 2012.
278 p. ; 21cm

Tese (doutorado) - Universidade Federal de Santa Catarina, Centro Tecnológico. Programa de Pós-Graduação em Engenharia e Gestão do Conhecimento.

Inclui referências

1. Engenharia e Gestão do Conhecimento. 2. Sistema setorial de inovação. 3. Dinâmica de sistemas. 4. Modelo de Simulação. 5. Indústria de Software. I. Varvakis, Gregório. II. Kern, Vinícius. III. Universidade Federal de Santa Catarina. Programa de Pós-Graduação em Engenharia e Gestão do Conhecimento. IV. Título.

Mauricio Uriona Maldonado

DINÂMICA DE SISTEMAS SETORIAIS DE INOVAÇÃO: Um modelo de simulação aplicado no Setor Brasileiro de Software

Esta Tese foi julgada adequada para obtenção do Título de Doutor em Engenharia e Gestão do Conhecimento e aprovada em sua forma final pelo Programa de Pós-Graduação em Engenharia e Gestão do Conhecimento da Universidade Federal de Santa Catarina.

Florianópolis, 24 de agosto de 2012.

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A mis padres, Carlos y Ruth

AGRADECIMENTOS

Em primeiro lugar gostaria de agradecer à Universidade Federal de Santa Catarina e ao Programa de Pós Graduação em Engenharia e Gestão do Conhecimento (PPEGC) por ter me dado a oportunidade de realizar o Doutorado, durante esses 4 anos aprendi mais do que poderia ter imaginado. Da mesma forma agradeço ao PEC-PG e ao CAPES/PROF por ter financiado meus estudos.

Agradeço também ao Prof. Gregório Varvakis, o "Grego" por ter acreditado em mim quando aceitou ser meu Orientador de Doutorado. Eu vinha de realizar o mestrado no EGC com ele, e o fato de receber mais uma vez a confiança dele foi inspiradora para mim. O Grego sempre falou sobre a relação de amor e ódio com os "Mauricios" da vida dele, de certa forma me sinto orgulhoso de ser um deles. O Grego me ensinou mais do que um Professor poderia ter ensinado, pois ajudou-me a formar também como ser humano, por isso fico eternamente grato a ele.

De forma imensa, agradeço aos professores do PPEGC que me ofereceram apoio, conhecimento e principalmente curiosidade para me tornar melhor pesquisador. São eles: o Prof. Vinícius Kern, meu co-orientador; o Prof. Roberto Pacheco; o Prof. Neri dos Santos; o Prof. Paulo Selig; a Profa. Andrea Steil; o Prof. Tarcisio Vanzin; o Prof. Richard Perassi.

Agradeço a ajuda e inspiração do Prof. Ricardo Pietrobon, da Duke University, que desde 2009 me ajudou imesamente com o desenvolvimento da Tese. Sem o apoio dele, este trabalho doutoral teria sido certamente mais dificil de finalizar. O Ricardo sempre me auxiliou quando precisei e agradeço as longas horas de conversação que tivemos junto com eles e com os membros da sua equipe.

Deixo também um agradecimento especial ao Prof. Raimundo Nonato Macedo dos Santos da UFPE, quem me inspirou curiosidade sobre a ciência e a pesquisa e quem me ensinou, além das ferramentas da bibliometría e cientometría, uma mais valiosa, a criticidade.

Agradeço ao Prof. Pablo Bittencourt, do Departamento de Economia e Relações Internacionais da UFSC, quem me ofereceu muito do seu tempo para discutir os pontos mais complexos da minha Tese. O Pablo sempre se dispôs a me auxiliar quando tive dúvidas ou questionamentos sobre meu trabalho. Fico muito grato com ele.

Agradeço à Caroline Vaz, que foi de vital importância nesse último ano de Doutorado, pois me ofereceu não só a ajuda e o apoio sempre que precisei senão também o carinho e a compreensão para me inspirar a fazer um melhor trabalho e uma melhor pessoa.

À meus queridos colegas e amigos do Núcleo de Gestão para Sustentabilidade (NGS), o grupo de pesquisa do Prof. Grego e do Prof. Selig, que me recebeu com os braços abertos desde que iniciei meu mestrado e que durante o doutorado continuou me oferecendo um espaço de crescimento, de amizade e como alguns de nós costumávamos falar, um espaço de família para a grande maioria da equipe do NGS. Também fui testemunha da evolução que teve o grupo de pesquisa durante esses anos todos, conheci de certa forma diferentes “gerações” de NGS e tenho certeza que as novas continuarão com o legado de amizade e profissionalismo que lhe caracteriza. Posso citar muitos dos amig@s que me ajudaram ao longo desse trabalho, à Renata Jorge Vieira, ao Eduardo Giugliani, à Mohana Faria de Sá, à Fabiana Raupp, ao Alexandre Soratto, ao André Donadel, ao Leonardo Leocádio com quem tive a oportunidade de trabalhar em dois projetos junto ao NGS, ao Guillermo Dávila, ao Douglas Kaminski e à Jane Santos. Da nova geração, recordarei sempre aos amigos Segundo Benitez, Ana Santos, Ruth Reategui, Danny Inomata, Ketry Farias dos Passos, Sirlene Pintro, Maurício Manhães, Maria Augusta Orofino, Diego Kurtz e Jaque Rossato.

Agradeço também aos amigos e colegas que conheci no exterior, quando da minha participação em congressos e cursos relacionados com a Tese. Em especial agradeço o apoio do José Miguel Natera e do Amir Ta, bem como de vários outros amigos: Alejandro Lavopa, Rodrigo Cortez e Flávio Peixoto.

Agradeço à rede Globelics, por ter me dado a oportunidade de participar na *PhD Academy of Innovation and Economic Development* na Finlândia em 2011 por meio de auxílio financeiro com hospedagem e transporte aéreo. Neste curso tive a oportunidade de conhecer grandes pesquisadores aos quais também agradeço: B.A. Lundvall, Jorge Niosi, Franco Malerba, Judith Sutz, José Cassiolato. Desde então mantive contato com a rede e participei dos congressos anuais também com apoio financeiro da Globelics, agradeço a eles por esse apoio.

Agradeço também à *System Dynamics Society*, a qual me deu a oportunidade de participar em várias versões dos seus congressos, nos quais recebi ajuda financeira. Nesses eventos tive a oportunidade de conversar com muitos especialistas em dinâmica de sistemas sobre meu trabalho e recebi *feedbacks* importantes, são eles: John Sterman, John Morecroft, Jay W. Forrester principalmente.

Gostaria de agradecer à minha família no Brasil que fez possível e mais agradável a minha estância durante o mestrado e o doutorado, em especial ao meu primo irmão Edwin Maldonado, à sua esposa Denise, aos meus sobrinhos Andy e Sindy, à minha prima Gabriela e o marido Hilário, à minha Tia Gaby, à minha prima Ruth (Toty) e ao meu sobrinho Luca. Durante esses anos todos recebi deles mais do que poderia ter pedido e agradeço a cada um pelo cuidado e carinho que tiveram comigo.

Por fim, e não menos importante, aos meus pais, aos quais dedico este trabalho, pelo apoio que me foi dado sempre. Minha gratidão a eles é eterna assim como o meu desejo de poder retribuir-lhes pelo menos em parte com o esforço, sacríficio e novos desafios que vem pela frente.

The trend in science...has been toward reductionism, a constant breaking things down into little bitty pieces...What people are finally realizing is that that process has a dead end to it. Scientists are much more interested in the idea that the whole can be greater than the sum of the parts…

(Doyne Farmer)

RESUMO

As empresas inovam por meio de interações dinâmicas e complexas com outros agentes de conhecimento, formando um sistema de inovação. No entanto, estudos prévios não levam em consideração as propriedades dinâmicas de tais sistemas. Este trabalho objetiva incrementar a compreensão sobre os efeitos dinâmicos do conhecimento e aprendizado na atividade inovativa ao desenvolver um modelo dinâmico do sistema de inovação. Um novo *framework* foi construido, que inclui os componentes e relações essenciais de um sistema de inovação, a partir de uma revisão sistemâtica de literatura. O *framework* foi instanciado para o caso do Setor Brasileiro de Software no Brasil e formalizado num model de dinâmica de sistemas, utilizando dados da Pintec e da literatura prévia. Esta pesquisa proveê explicações sobre como o conhecimento e o aprendizado afetam a dinâmica dos sistemas de inovação e, a partir do modelo, demonstra a dinâmica do mesmo ao realizar experimentos pontuais.

Palavras-chave: Sistema Setorial de Inovação. Dinâmica de Sistemas. Modelo de Simulação. Indústria de Software

ABSTRACT

Firms innovate through complex and dynamic interactions with other knowledge agents forming an Innovation System. However, most previous studies have not taken into account the dynamic properties of such systems. Thus, this work aims to improve the understanding of the dynamic effects of knowledge and learning on innovative activities by designing a comprehensive innovation system dynamics model. Thus, a new framework is developed including the essential components and linkages of an innovation system, by means of a systematic review of literature. The framework was instantiated for the case of the Software Sector in Brazil and formalized through the use of a system dynamics model, using data from PINTEC and previous literature. This research provides explanations of how knowledge and learning affect the dynamics of innovation systems and, through the model, demonstrates the dynamics of the system by performing punctual experiments.

Keywords: Sectoral Innovation Systems. System Dynamics. Simulation Model. Software Industry.

RESUMEN

Las empresas innovan a través de interacciones complejas y dinámicas con varios agentes de conocimiento, formando un Sistema de Innovación. Sin embargo, la mayor parte de los estudios no considera las propiedades dinámicas de esos sistemas. Este trabajo tiene como objetivo incrementar la comprensión de los efectos dinámicos del conocimiento y del aprendizaje en las actividades innovadoras por medio de un modelo dinámico para sistemas de innovación. De esta forma, un nuevo framework es desarrollado incluyendo los componentes y relaciones esenciales de un sistema de innovación por medio de una revisión sistemática. El framework luego es instanciado para el caso del Sector Brasilero de Software a partir de una revisión de literatura específica y de datos de PINTEC. Este trabajo ofrece explicaciones sobre como el conocimiento y el aprendizaje afectan la dinámica del sistema de innovación y con el uso del modelo, demuestra los cambios en esa dinámica al realizar experimentos puntuales.

Palabras Clave: Sistema Sectorial de Innovación. Dinámica de Sistemas. Modelo de Simulación. Industria de Software.

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1 INTRODUÇÃO

Este trabalho nasce a partir da crescente preocupação de gestores de políticas públicas, de acadêmicos e pesquisadores e de organizações internacionais, em garantir e potencializar o bem estar social e econômico nacional e regional por meio do uso do conhecimento e da inovação[1] como geradores de riqueza.

A Tese se desenvolve no contexto da inovação como fenômeno sistêmico, ou seja, na noção de que a geração de inovações é o resultado de interdependências entre um conjunto de atores, instituições, conhecimentos científicos, tecnológicos e daqueles baseados na prática.

O sistema de inovação, termo como é conhecido na literatura, tem sido alvo de um número cada vez maior de estudos de teor científico (EDQUIST; HOMMEN, 2008), pois a compreensão do funcionamento do sistema de inovação ajuda na formulação de melhores e mais efetivas políticas públicas visando o benefício final da sociedade.

A presente Tese contribui com esse campo de estudo ao incrementar a compreensão da dinâmica do sistema de inovação, por meio de um *framework* conceitual, por meio da explicitação do *framework* num modelo de simulação – baseado no conceito dos sistemas complexos – e por meio de inferências realizadas a partir dos resultados dessas simulações.

Para isto, a Tese se fundamenta nos trabalhos seminais propostos por Freeman (1987), Lundvall (1992) e Nelson (1993) e nas correntes da economia evolutiva, da economia institucional, da racionalidade limitada e da teoria termodinâmica (NIOSI; BELLON, 1994).

Especificamente a Tese estuda um sistema de inovação na dimensão setorial, dimensão inicialmente proposta por Malerba (2002). O setor escolhido é o Setor de *Software* no Brasil. O setor de *software* pertence ao grupo de serviços intensivos em conhecimento (KIBS) e tem recebido uma atenção considerável a nível internacional e nacional (ROSELINO, 2006; BRITTO; STALLIVIERI, 2010; DIEGUES; ROSELINO, 2011).

O *framework* é composto por componentes e relações e construído a partir de uma revisão sistemática de literatura. Assim, o modelo de simulação, baseado na metodologia da dinâmica de sistemas,

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[1] Para este trabalho, define-se inovação a partir do Manual de Oslo como “a implementação de um produto (bem ou serviço) novo ou significativamente melhorado, ou um processo, ou um novo método de marketing, ou um novo método organizacional nas práticas de negócios, na organização do local de trabalho ou nas relações externas” (OECD, 2005).

explicita os componentes e relações identificados previamente no *framework* e é instanciado para o caso do setor de *software* no Brasil, salientando os processos de aprendizagem e de conhecimento. O resultado é um *framework* de modelagem e um modelo de simulação que auxilia na análise de comportamentos dinâmicos dos sistemas de inovação.

Por sua vez, a estruturação do trabalho é também diferente da forma tradicional. O corpo do texto a seguir apresenta uma versão condensada em língua portuguesa e a versão do Apêndice A apresenta a versão extensa do trabalho, em língua inglesa.

De forma específica, este capítulo apresenta os principais elementos norteadores do trabalho, problema, objetivos, proposta metodológica e aderência teórica-conceitual com o Programa de Pós-Graduação em Engenharia e Gestão do Conhecimento da Universidade Federal de anta Catarina, finalizando com a estrutura do documento.

1.1 DEFINIÇÃO DO PROBLEMA

Sendo a inovação uma das principais formas de alavancar o desenvolvimento econômico, trabalhos relacionados com seu estudo tem se incrementado amplamente nos últimos anos. A inovação é considerada na atualidade como um processo que obedece a uma complexa interrelação de atores além da empresa – sendo a empresa considerada como a unidade na qual as inovações acontecem – e um número também significativo de relações entre esses atores, as quais podem ser caracterizadas como fluxos de informação, de conhecimento, de capital e de produção (NIOSI, 2002; OECD, 2002).

A partir de trabalhos seminais como os de List (1885) e Schumpeter (1934) e de forma mais contemporânea, os trabalhos de Freeman (1987), Lundvall (1992) e Nelson (1993), a inovação passa a ganhar um papel importante na mesa de formulação de políticas públicas, contudo, é nas últimas décadas que o fenômeno da "inovação" ganha uma difusão a nível global. O principal motivo para essa massiva difusão centra-se na evidência de que a inovação traz efetivamente benefícios para as regiões e países que a sabem gerar.

É o caso dos países e regiões industrializados ou desenvolvidos, os quais apresentam altos índices de intensidade tecnológica, progresso científico, produtividade industrial e em serviços e, ao mesmo tempo, altos índices de desenvolvimento humano e bem estar social e econômico (INSEAD, 2012; WEF, 2012).

No caso de países e regiões em desenvolvimento ou em *catching-up*, como são conhecidos na literatura, à inovação ainda é um processo descontínuo com baixa geração, difusão e uso de conhecimento economicamente útil (LUNDVALL *et al.*, 2009).

A abordagem de sistemas de inovação surge a partir de um trabalho produzido por Christopher Freeman em 1982 no contexto de um conjunto de debates sobre as políticas industriais, que estavam acontecendo na Europa e que eram promovidos principalmente pela Organização para a Cooperação e Desenvolvimento Econômico (OECD) (SHARIF, 2006). Posteriormente, são Freeman (1987), Lundvall (1992) e Nelson (1993) os que publicam os primeiros trabalhos abordando a inovação como fenômeno sistêmico.

Desde esse início, o campo de estudo de sistemas de inovação tem crescido significativamente, tanto no âmbito acadêmico, mensurado pelo número de publicações bem como no âmbito da *policy making*, mensurado pelos governos e organismos que utilizam o conceito de sistema de inovação para formular políticas públicas (URIONA MALDONADO; SANTOS; VARVAKIS, 2012).

Contudo, literatura mais recente tem sugerido que os sistemas de inovação são sistemas complexos, devido a que eles estão sujeitos a mudanças contínuas de comportamento (NIOSI, 2011), produzidas principalmente por mudanças na configuração interna do sistema (LIU; WHITE, 2001). Assim também, estudos têm sugerido que a eficiência do funcionamento desses sistemas depende das mudanças e nas velocidades de transmissão de fluxos de conhecimento, de informação, de capital e humano entre seus componentes (NIOSI, 2002; OECD, 2002; ZHUGE, 2002; LABIAK, 2012).

Isto apresenta um desafio para a comunidade científica e política interessada no tema, pois a maior parte dos estudos existentes foca apenas em aspectos estáticos e não na dinamicidade do sistema – produto da transmissão de fluxos entre os componentes do sistema.

Por sua vez, os fluxos descritos acima e em especial os fluxos de conhecimento são produto de processos de aprendizagem e da geração, disseminação e uso do conhecimento (BONTIS; CROSSAN; HULLAND, 2002; VERA; CROSSAN, 2003). Neste sentido, estudos focados nos processos de aprendizagem e conhecimento poderiam auxiliar a incrementar a compreensão do complexo comportamento do sistema de inovação, assim, apresenta-se a pergunta de pesquisa que norteia o presente trabalho:

- Como os processos de aprendizagem e conhecimento afetam a dinâmica da atividade inovativa?

Considerando, que o marco no qual se insere o presente trabalho é o sistema setorial de inovação, existem também perguntas adicionais que são necessárias para poder responder a pergunta de pesquisa geral, são elas:

- Qual é o papel dos fluxos de conhecimento e da aprendizagem na atividade inovativa?
- Como as interações entre conhecimento e aprendizagem alteram o comportamento do sistema setorial?
- Como políticas alternativas podem levar a um melhor desempenho?

1.2 OBJETIVOS

De acordo com o que foi mencionado anteriormente, o objetivo principal deste trabalho é oferecer uma melhor compreensão sobre como o conhecimento e os processos de aprendizagem afetam a dinâmica das atividades inovativas, sob a visão dos sistemas de inovação setoriais.

Da mesma forma, os objetivos específicos são:

- Identificar os principais componentes e relações genéricas de um sistema de inovação.
- Sintetizar os componentes e relações identificados num *framework* de modelagem.
- Construir um modelo de simulação, basado no *framework* de modelagem e instanciá-lo para o caso do setor de software no Brasil.
- Realizar experimentos de simulação para testar os efeitos do conhecimento e dos processos de aprendizagem na dinâmica do sistema setorial de software do Brasil.

1.3 ADERÊNCIA DA PESQUISA COM A ENGENHARIA E GESTÃO DO CONHECIMENTO

O *framework* proposto tem como objetivo analisar – de forma estática – como o conhecimento é gerado, disseminado e usado num determinado contexto setorial (Setor de *Software*) e num contexto geográfico (o Brasil). Desta forma, o modelo de simulação oferece um segundo nível de análise – uma análise dinâmica – sobre o fluxo do conhecimento no contexto em questão.

Neste contexto, o presente trabalho se enquadra dentro da área de pesquisa em engenharia e gestão do conhecimento, pois inicialmente constroem-se objetos (o *framework* e o modelo de simulação) para viabilizar a compreensão dos processos de geração, disseminação e uso de conhecimento, a partir de uma visão da engenharia de conhecimento. Posteriormente realizam-se inferências relacionadas com as implicações teóricas e práticas de diferentes estruturações de geração, disseminação e uso de conhecimento, por meio da simulação, uma ferramenta utilizada pela gestão do conhecimento.

Neste sentido, a Tese apresenta uma visão conjunta entre a engenharia e a gestão do conhecimento, se aproveitando de ferramentas e metodologias advindas de ambas as áreas, para analisar o objeto do estudo em questão, um sistema setorial de inovação.

Por fim, a aderência da Tese nas linhas de estudo da Engenharia e Gestão do Conhecimento também pode ser observada pela existência de trabalhos correlatos recentes com foco na temática de sistemas de inovação são eles: o trabalho de Labiak (2012) que descreve uma análise de fluxos de conhecimento para sistemas regionais de inovação, o trabalho de Sartori (2011) que descreve mecanismos de governança para agências de fomento em sistemas de inovação, o trabalho de Giugliani (2011) que descreve um modelo de governança orientado para Parques Científicos e Tecnológicos e o trabalho de Sá (2011) que descreve uma avaliação de práticas de gestão do conhecimento em parques tecnológicos.

1.4 ESTRUTURA DO TRABALHO

O trabalho se estrutura da seguinte forma: o corpo do trabalho apresenta uma versão enxuta e condensada da Tese, incluindo a introdução (este capítulo), o referencial teórico (Capítulo 2), os procedimentos metodológicos (Capítulo 3), os resultados (Capítulo 4), as conclusões e recomendações (Capítulo 5) e por fim as Referências.

No Apêndice A, encontra-se a versão extensa do trabalho, incluindo por sua vez sete capítulos. A versão do Apêndice A, redigida em língua inglesa visando ampliar a disseminação do trabalho em questão a nível internacional.

No Apêndice B, apresenta-se o modelo de carta utilizado para solicitar estudos adicionais aos autores dos artigos selecionados na revisão sistemática de literatura.

Por fim, o Apêndice C, apresenta uma contextualização do setor de *software* no Brasil, considerando o perfil estrutural do setor bem como o marco de políticas setoriais e nacionais do mesmo.

2 REFERENCIAL TEÓRICO

Este capítulo apresenta a versão condensada do principal referencial teórico utilizado na Tese. O conteúdo na versão extensa encontra-se no Apêndice A. Desta forma o capítulo inicia com uma descrição sobre a literatura de sistemas de inovação, e em particular de sistemas setoriais de inovação. A segunda parte do capítulo apresenta os principais conceitos sobre dinâmica de sistemas.

2.1 SISTEMAS SETORIAIS DE INOVAÇÃO

Há na atualidade um grande número de definições de sistema de inovação, assim, Freeman (1987) entende que um sistema de inovação está formadas pelas redes de instituições públicas e privadas que têm por objeto a importação, modificação e difusão de novas tecnologias, já para Lundvall (1992) um sistema de inovação compõe-se de todos os elementos e relações que interagem na produção, difusão e uso do conhecimento novo e economicamente útil, e para Nelson (1993) esse sistema se compõe de um conjunto de instituições que, na medida em que interagem, determinam o desempenho inovador do setor privado.

Tomando como base as definições previamente descritas, o conhecimento (a geração, disseminação e uso) está fortemente entrelaçado com a atividade inovativa. A literatura aponta esse entrelaçamento, como fluxos de conhecimento, a partir dos quais diferentes formas de aprendizagem organizacional podem ser identificadas, são elas a realização de atividades de P&D, treinamento e capacitações, contratação de pessoal e o uso de conhecimento préviamente armazenado (BONTIS; CROSSAN; HULLAND, 2002; LASTRES; CASSIOLATO; MACIEL, 2003; VERA; CROSSAN, 2003; CASSIOLATO; LASTRES, 2008).

O sistema de inovação, portanto, está composto por diferentes fluxos de conhecimento, advindos das atividades descritas acima, conectando os diferentes atores e processos de geração, disseminação e uso de conhecimento. Essas conexões ou relações, produzem mecanismos de autoregulação e retroalimentação no sistema, atribuindo-lhe características dinâmicas, ou seja, a capacidade de mudar de comportamento ao longo do tempo (CARLSSON *et al.*, 2002).

Em adição, trabalhos seminais como os de Arrow (1962) e Nelson (1971) atraem especial atenção ao componente de política pública, em especial às políticas de ciência, tecnologia e inovação. São essas políticas as que geram a dinâmica no sistema de inovação e as que servem de mecanismos com os quais o desempenho do sistema pode ser alterado a favor da sociedade.

Com base no exposto anteriormente, os sistemas de inovação são sistemas complexos pois dependem de mecanismos de autoregulação com os quais o sistema evolui e se adapta às mudanças (JANSZEN; DEGENAARS, 1998; GARCIA; CALANTONE; LEVINE, 2003; LEE; VON TUNZELMANN, 2005; LIN; TUNG; HUANG, 2006; DANGELICO; GARAVELLI; PETRUZZELLI, 2010; NIOSI, 2011; TAYARAN, 2011).

Dentre a literatura de sistemas de inovação, existem diferentes propostas de dimensões de análise além da dimensão nacional, são elas, a dimensão regional (ou sistema regional de inovação), proposta por P. Cooke e outros (COOKE, 1992; COOKE; URANGA; ETXEBARRIA, 1997; 1998; NIOSI, 2010); a dimensão setorial ou sistema setorial de inovação, proposta por Malerba (2002); e por fim a dimensão tecnológica ou sistema tecnológico de inovação (CARLSSON; STANKIEWICZ, 1991; CARLSSON *et al.*, 2002).

A abordagem utilizada na presente Tese é a de sistema setorial de inovação. Esta abordagem ressalta características sistêmicas dentro de um setor determinado. O fato de analisar um setor específico facilita a compreensão da estrutura dinâmica do sistema, pois como salienta Malerba (2002) o setor é a unidade de análise mais adequada para verificar a consistência de políticas e trajetórias tecnológicas dentro de um país, pois os agentes ou atores do setor compartilham uma mesma base de conhecimentos, um conjunto similar de tecnologias, um conjunto similar de estruturas de mercado e por fim, de um único marco de política específicamente setorial e de um conjunto similar de políticas nacionais e regionais.

Por fim, os setores também são afetados por um determinado regime tecnológico. O regime tecnológico determina as características contextuais nas quais a geração, disseminação e uso do conhecimento acontecem, dentro do sistema e ao mesmo tempo, tenta explicar o comportamento do sistema de inovação setorial a estímulos internos (comportamento endôgeno) ou a estímulos externos (comportamento exôgeno) (NELSON; WINTER, 1982; CASTELLACCI, 2007; MALERBA; NELSON, 2011).

O regime tecnológico compõe-se de quatro características: 1) a natureza da base de conhecimento do setor em estudo (se é de natureza mais tácita ou mais explícita, se é de natureza mais formal ou mais prática, etc.); 2) o nível de oportunidade tecnológica (oportunidade de entrada ao setor por novos entrantes); 3) o nível de apropriabilidade tecnológica (a capacidade de manter as inovações protegidas da imitação, ou seja, por mecanismos legais ou pela complexidade dos conhecimentos produzidos); e por fim 4) o nível de cumulatividade de conhecimento (a capacidade de dependência das inovações atuais em conhecimentos prévios, efeito conhecido como *path dependency*).

No Apêndice A - Capítulo 2 apresenta-se uma discussão mais ampla sobre as principais características dos sistemas setoriais de inovação.

2.2 DINÂMICA DE SISTEMAS

A Dinâmica de Sistemas (DS) é uma metodologia de modelagem que serve para testar como a estrutura de sistemas complexos reage a estímulos externos e internos (exôgenos e endôgenos). Desenvolvida no *Massachussets Institute of Technology* (MIT) na década de 1950 por Jay W. Forrester, a metodologia ganhou relevância na área da pesquisa operacional nas últimas décadas pela facilidade de representar estruturas complexas e de explicar os mecanismos que produzem o comportamento dinâmico.

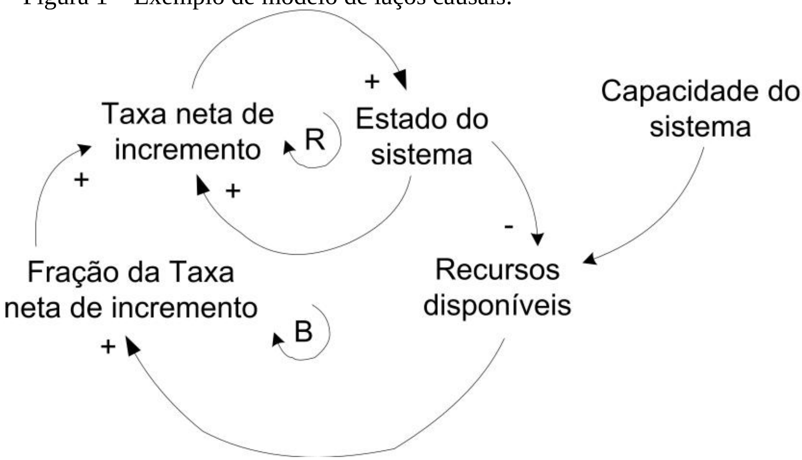
A Dinâmica de Sistemas se fundamenta na aplicação da matemática diferencial e na construção de sistemas de equações diferenciais que, com a ajuda de softwares especializados como o iThink® da Isee Systems e o Vensim® da Ventana Systems, são resolvidos por trás da sua interface gráfica. Os sistemas de equações – que os softwares resolvem com base a métodos numéricos – são compostos por variáveis de estado (estoques), taxas (fluxos) e variáveis de tempo, gerando – na resolução dos sistemas de equações – o comportamento dinâmico e não-linear do sistema (FORRESTER, 1971; STERMAN, 2000).

O principal conceito relacionado com a metodologia da dinâmica de sistemas é o de retroalimentação ou simplesmente realimentação. Este fenômeno se refere ao processo pelo qual a reação de uma determinada variável acaba gerando um comportamento em cadeia, resultando em mudanças nos comportamentos de outras variáveis, afetando em última instância o comportamento da primeira, fechando uma malha de realimentação.

Diversos autores têm sugerido que essa propriedade – a realimentação – é a principal propriedade dos sistemas complexos, portanto, a metodologia de dinâmica de sistemas consegue se aproximar em grande maneira ao comportamento dos sistemas reais (FORRESTER, 1989; LYNEIS, 2000; STERMAN, 2000).

A Dinâmica de Sistemas é composta por dois tipos de modelos: os modelos de laços causais ou *causal loops diagrams* (CLD); e os modelos de estoques e fluxos. Os modelos de CLD ajudam na identificação de malhas ou *loops* dominantes sobre outros, o que acaba gerando a dinâmica do sistema. A figura 1 apresenta um exemplo de modelo CLD utilizando a notação da dinâmica de sistemas.

Figura 1 – Exemplo de modelo de laços causais.



Fonte: Elaborado pelo autor

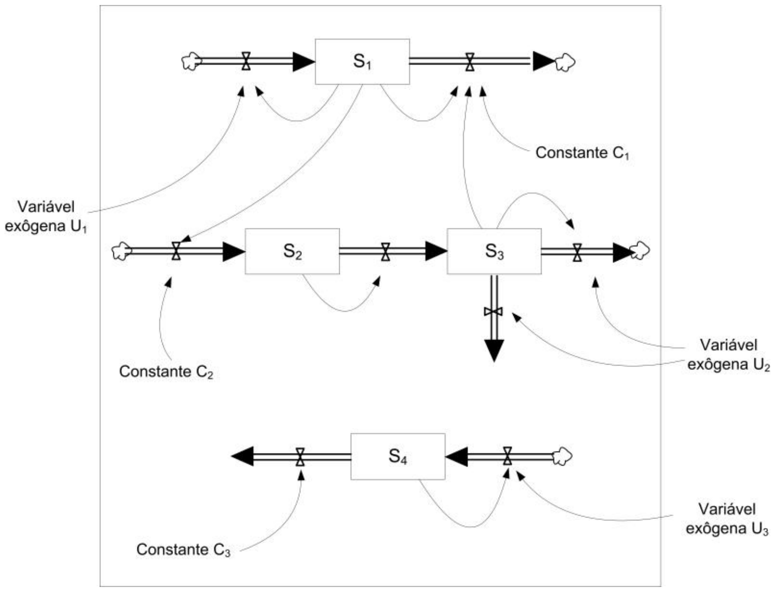
No exemplo da Figura 1, apresentam-se duas malhas de realimentação ou *loops*, uma positiva, representada pela letra “R” e uma negativa, representada pela letra “B”.

Já os modelos de estoques e fluxos servem para traduzir as malhas de realimentação em equações matemáticas as quais por sua vez, servem para realizar experimentos de simulação sobre o comportamento do sistema a estímulos provocados pelo modelador. A Figura 2 apresenta um exemplo de modelo de estoques e fluxos utilizando a nomenclatura da dinâmica de sistemas.

Conforme a Figura 2, os estoques são representados por retângulos que acumulam informação, materia ou energia. A acumulação depende da diferença de velocidade entre o caudal de entrada (fluxo de entrada representado por uma seta entrando no acumulador) e o caudal de saída (fluxo de saída representado por uma seta saindo do acumulador).

Além das variáveis de estoque e de fluxo, a Figura 2 também apresenta as constantes e variáveis exógenas, aquelas cujo valor é considerado constante e não dependente das interrelações internas ou endógenas no sistema.

Figura 2 – Exemplo de modelo de estoques e fluxos.



Fonte: Elaborado pelo autor

Por fim, um conjunto importante de pesquisas sustenta que a dinâmica de sistemas pode auxiliar na compreensão, mensuração e gestão de sistemas de inovação, sistemas que são tidos como complexos. Neste sentido, autores como Niosi (2011), Tayaran (2011), Dangelico et al. (2010), Lin et al. (2006), Lee e von Tunzelmann (2005), Garcia et al. (2003) e Janszen e Degenaars (1998) entre outros têm se apoiado nas ferramentas da dinâmica de sistemas para modelar aspectos relacionados com os componentes e relações que fazem parte do sistema de inovação.

Desta forma, a capacidade de identificar as malhas de realimentação positivas e negativas que geram a dinâmica do sistema de inovação bem como a capacidade de representá-lo como um conjunto de acumulações e fluxos diversos auxilia na melhor gestão de políticas e estratégias que venham a melhorar o desempenho sistêmico.

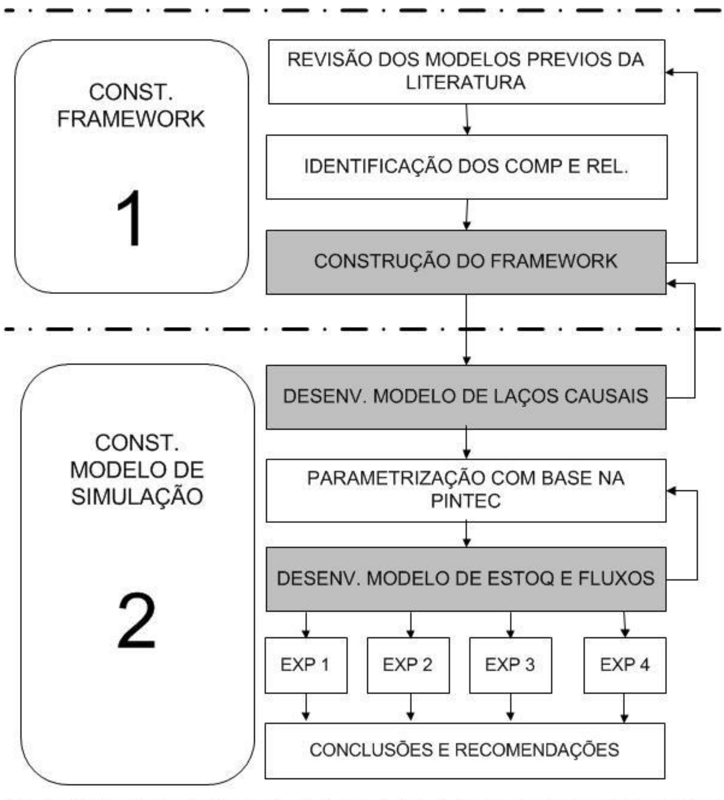
Portanto, a Tese se propõe apresentar uma aplicação de modelagem completa sobre um sistema de inovação específico: o sistema setorial de inovação do setor de *software* no Brasil.

No Apêndice A (Capítulo 3), descreve-se em detalhe a base teórico-metodológica da dinâmica de sistemas, bem como a linguagem e simbologia utilizada para modelar e simular sistemas complexos utilizando dinâmica de sistemas.

3 PROCEDIMENTO METODOLÓGICO

Este capítulo apresenta a versão condensada do procedimento metodológico utilizado na Tese. O conteúdo na versão extensa encontra-se no Apêndice A, Capítulo 4. A seguir apresentam-se as quatro fases que compõem esta Tese, a construção do *framework* de modelagem, o desenvolvimento do modelo de laços causais, o desenvolvimento do modelo de estoques e fluxos e por fim, a condução de experimentos de simulação conforme a Figura 3.

Figura 3 – Fases da pesquisa.



Fonte: Elaborado pelo autor

3.1 *FRAMEWORK* DE MODELAGEM

A fase 1 tem como objetivo a construção de um *framework* de modelagem, desenvolvido a partir de uma revisão da literatura relacionada com modelos prévios. Para isto, o método selecionado foi a revisão sistemática de literatura, que oferece um procedimento altamente reproduzível e transparente para identificar e selecionar estudos dentro de um escopo e contexto de literatura com alto grau de exaustividade e confiabilidade (KHAN *et al.*, 2001; PETTICREW; ROBERTS, 2006; CROSSAN; APAYDIN, 2010).

O objetivo da revisão sistemática de literatura foi o de realizar um censo sobre toda a literatura publicada entre 1990 e 2009 relacionada com a modelagem de sistemas de inovação. Esta revisão serviu para fazer o levantamento de vários modelos propostos na literatura que propõem estruturas de modelos para sistemas de inovação. O *framework* foi desenvolvido a partir dessa revisão, o qual tenta descrever os principais componentes e relações – estrutura – de um sistema de inovação. Essa estrutura logo será aprimorada e testada nas fases subsequentes desta pesquisa.

3.2 MODELO DE LAÇOS CAUSAIS

A segunda fase da presente pesquisa é o desenvolvimento de um modelo de laços causais (CLD), baseado no *framework* de modelagem.

A construção do modelo CLD seguiu as recomendações de Sterman (2000) e Morecroft (2007). Os CLDs são utilizados para identificar malhas de realimentação ou laços causais que conectam os diferentes componentes do sistema. As malhas podem ser de reforço positivo (quando existe um efeito de crescimento em cadeia) ou de balanço negativo (quando existe um efeito de decrescimento em cadeia).

A teoría da dinâmica de sistemas salienta que os efeitos combinados de reforço e balanço de várias malhas ou laços causais são os que determinam o comportamento complexo observado em sistemas reais.

Assim, os CLDs oferecem possíveis explicações sobre as causas de determinados comportamentos.

3.3 MODELO DE ESTOQUES E FLUXOS

A terceira fase desta pesquisa foi à construção de um modelo formal de simulação, usando a linguagem de estoques e fluxos oferecida pela metodologia da dinâmica de sistemas (STERMAN, 2000).

Para isto, os laços de realimentação dos CLDs devem ser transformados em linguagem de simulação. O modelo de estoques e fluxos oferece uma capacidade adicional na análise de sistemas, a capacidade de realizar experimentos quantitativos de simulação.

O modelo de estoques e fluxos foi instanciado com dados da Pesquisa Industrial de Inovação Tecnologica (PINTEC), das edições 2005 e 2008. Os dados coletados da PINTEC-2005 e da PINTEC-2008 foram específicamente selecionados para o Setor de *Software* no Brasil (IBGE, 2007; 2010).

Os dados serviram para alimentar variáveis, parámetros e constantes no modelo de estoques e fluxos bem como para realizar a provas de verificação de consistência e os experimentos de simulação selecionados.

3.4 EXPERIMENTOS DE SIMULAÇÃO

Por fim, foram realizados quatro grupos de experimentos de simulação destinados a verificar a aplicabilidade do modelo desenvolvido, considerando como ambiente de aplicação o sistema setorial de *software* no Brasil. Para isto, diferentes condições relacionadas com o regime tecnológico do sistema setorial em estudo, são testadas.

Específicamente são testadas diferentes velocidades de aprendizagem e seus efeitos na dinâmica inovativa do setor de *software* (experimento 1), diferentes níveis de oportunidades tecnológicas (experimento 2), diferentes níveis de apropriabilidade tecnológica (esperimento 3) e por fim, diferentes níveis de cumulatividade de conhecimento (experimento 4).

4 RESULTADOS

Este capítulo apresenta a versão condensada dos resultados da presente pesquisa, são eles: o *framework* de modelagem, o modelo de laços causais, o modelo de estoques e fluxos e por fim, os experimentos de simulação. O conteúdo na versão extensa encontra-se no Apêndice A, Capítulos 5 e 6.

4.1 *FRAMEWORK* DE MODELAGEM

O *framework* de modelagem foi desenvolvido a partir de uma revisão sistemática de literatura, a qual objetivava a identificação de modelos ou forma de representação de sistemas de inovação previamente propostos na literatura.

O resultado foi a identificação de cinco componentes dentro do sistema de inovação e suas principais relações: o componente financeiro, o componente científico-tecnológico, o componente produtivo-tecnológico, o componente de mercado e o componente do capital humano e suas principais relações (fluxos de pessoal, fluxos de conhecimento e fluxos de capital).

A identificação de tais componentes e elementos foi realizada a partir da análise dos estudos prévios selecionados na revisão sistemática, definidos no Quadro 1.

Quadro 1 – Componentes do sistema de inovação.

Componente	**Referências**
Financeiro	(Johannessen, et al., 1997; Mohannak, 1999; Lopez-Ortega, 1997; Janszen & Degenaars, 1998; Hung, 2009; Shyu, et al., 2001; Stamboulis, 2008; Lee, 2006; Lee & von Tunzelmann, 2005; Ahlqvist & Inkinen, 2007)
Científico-tecnológico	(Galanakis, 2006; Hubner, 1996; Hung, 2009; Shyu, et al., 2001; Johannessen, et al., 1997; Janszen & Degenaars, 1998; Ahlqvist & Inkinen, 2007; Etzkowitz & Leydesdorff, 2000; Hsu, 2005; Mohannak, 1999; Lee, 2006; T. L. Lee & von Tunzelmann, 2005)
Produtivo-tecnológico	(Ahlqvist & Inkinen, 2007; Etzkowitz & Leydesdorff, 2000; Hsu, 2005; Hubner, 1996; Hung, 2009; Lee, 2006; Lee & von Tunzelmann,

	2005; Lopez-Ortega, 1997; Mohannak, 1999)
Mercado	(Galanakis, 2006; Hubner, 1996; Hung, 2009; Janszen & Degenaars, 1998; Johannessen, Dolva, & Olsen, 1997; Lee, 2006; Lee & von Tunzelmann, 2005; Lopez-Ortega, 1997; Shyu, Chiu, & Yuo, 2001)
Capital Humano	(Hung, 2009; Lee, 2006; Lee & von Tunzelmann, 2005; Lopez-Ortega, 1997; Shyu et al., 2001; Stamboulis, 2008)

Fonte: Elaboração própria com base na revisão sistemática

Além dos componentes do Quadro 1, também foram identificadas as relações principais entre eles. As relações são: Gastos em P&D, Gastos com outras fontes de conhecimento, Gastos com a introdução de inovações, Gastos com atividades de treinamento, Pessoal em atividades de P&D, C&T Externa, Investimentos externos, Aprendizagem via STI, Aprendizagem via DUI, Atratividade do produto e Atratividade do setor. Por fim, a estruturação de componentes e relações na forma do *framework* de modelagem é apresentada na Figura 4.

Na Figura 4, as linhas pontilhadas referem-se a fluxos de conhecimento entre dois componentes. As linhas contínuas referem-se a fluxos de capital, ou fluxos de pessoas, os quais relacionam dois ou mais componentes. Assim também, cada componente da Figura 1 se refere a um tipo de interação específica presente no sistema de inovação, no caso do componente financeiro, as interações acontecem na forma de fluxos de capital e na forma de fluxos de conhecimento e informação advindos do componente de mercado. No caso do componente científico-tecnológico, as interações acontecem na forma de fluxos de conhecimento, em particular de conhecimento STI[2] (conhecimento advindo de atividades formais de P&D), conforme a definição de Jensen et al. (2007) e de fluxos de capital, advindos dos gastos formais em P&D realizados pelas empresas.

Já para o caso do componente produtivo-tecnológico, as interações acontecem na forma de fluxos de conhecimento do tipo DUI[3]

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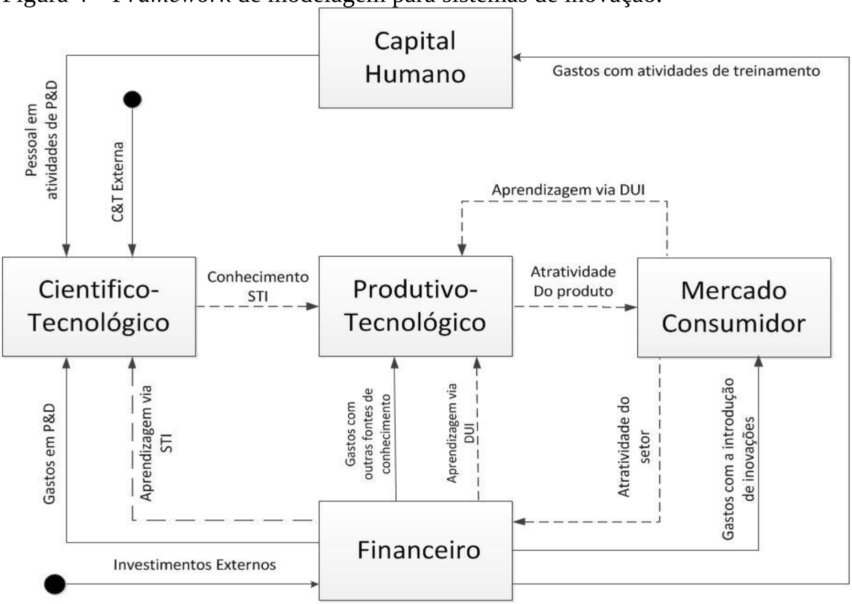
[2] O modo STI *(Science, Technology and Innovation)* de acordo com Jensen et al. (2007) representa a forma clássica ou tradicional de geração de conhecimento, aquela advinda da ciência e tecnologia, mais especificamente, das atividades de pesquisa e desenvolvimento (P&D).

[3] O modo DUI *(Doing, Using and Interacting)* de inovação, de acordo com Jensen et al. (2007) representa a forma de geração de conhecimento baseada na experiência e na prática.

(conhecimento advindo da aprendizagem na prática), conforme a definição de Jensen et al. (2007) e de gastos em atividades inovativas diferentes das de P&D, como por exemplo, em atividades de treinamento, de acquisição de maquinaria, equipamentos, *software*, etc. No componente de mercado, as interações referem-se tanto para fluxos de conhecimento, na forma de mecanismos para incentivar a difusão das inovações no mercado, bem como na forma de fluxos de capital, na forma de venda dos produtos lançados ao mercado.

Figura 4 – *Framework* de modelagem para sistemas de inovação.



Fonte: Elaborado pelo autor.

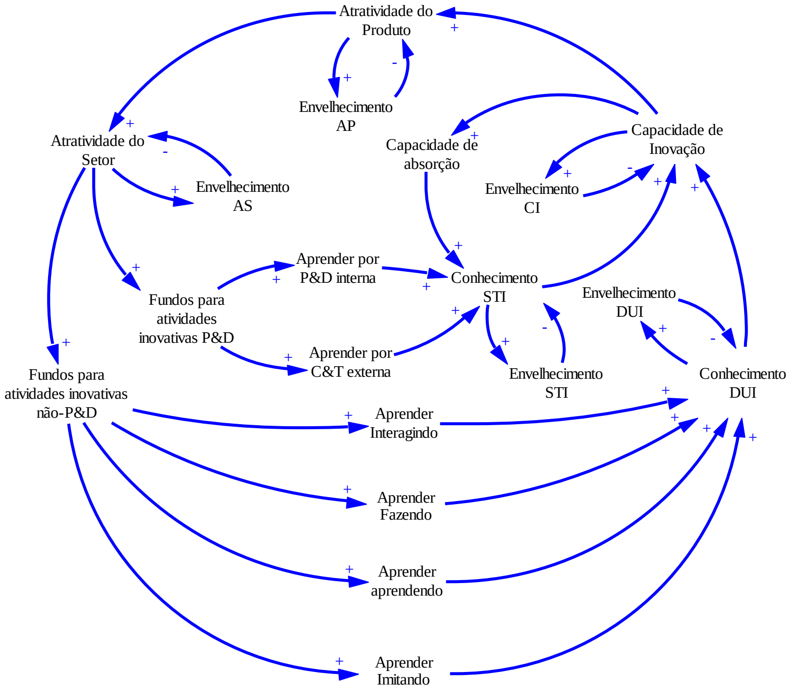
Por fim, o componente do capital humano interage com o componente científico-tecnológico ao oferecer pessoal qualificado para a realização das atividades de P&D. Considerando esta como uma forma especial de fluxo de conhecimento, do tipo mais tácito e incorporado nos cérebros desse pessoal.

4.2 MODELO DE LAÇOS CAUSAIS

Conforme a descrição do procedimento metodológico, a fase seguinte consistiu no desenvolvimento do modelo de laços causais ou modelo CLD. O modelo CLD está formado por treze malhas ou *loops* de realimentação, oito das quais são malhas de realimentação positiva e cinco de balanço negativo.

A interação conjunta das treze malhas ou *loops* é a responsável pela dinâmica do sistema de inovação, em específico do sistema de inovação setorial. Uma representação simplificada do modelo CLD apresenta-se na Figura 5.

Figura 5 – Modelo CLD simplificado de um sistema de inovação.



Fonte: Elaborado pelo autor.

Conforme a Figura 5, a dinâmica do sistema de inovação depende da dominância de uma ou várias malhas ou *loops* de realimentação sobre outras. Específicamente, as malhas identificadas representam diferentes formas de aprendizagem relacionadas com a geração de conhecimento do tipo STI (aprender por P&D interna e aprender por C&T externa), e relacionadas com a geração de conhecimento do tipo DUI (aprender interagindo, aprender fazendo, aprender aprendendo e aprender imitando).

Ambos os conhecimentos, STI e DUI geram uma determinada capacidade de inovação, que define o potencial inovador do sistema como um todo. Essa capacidade está relacionada com a atravidade dos produtos inovadores, quanto maior a capacidade de inovação maior será a atratividade do produto no mercado consumidor. Por sua vez, a dinâmica de mercado gerada pelo consumo e difusão de inovação gera uma determinada atratividade do setor como um todo, quando comparado com a atratividade de outros setores. A atratividade do setor serve como um indicador de desempenho como o qual os agentes do sistema decidem sobre investimentos futuros em atividades de P&D e também em atividades inovativas fora do escopo da P&D. Na medida em que o setor se apresente atrativo para os agentes, serão feitos novos investimentos em atividades inovativas fechando a dinâmica do sistema.

Por sua vez, cada um dos tipos de aprendizagem identificados gera uma dinâmica específica no sistema de inovação, para isto, a Tese considera vários tipos de aprendizagem.

Assim, os tipos de aprendizagem a partir de atividades de P&D (modo STI de inovação) levados em consideração nesta Tese são: a aprendizagem por P&D interna e a aprendizagem C&T externa. Já os tipos de aprendizagem a partir de atividades no modo DUI de inovação considerados são: a aprendizagem por interação, aprendizagem fazendo, aprendizagem por aprender e aprendizagem por imitação.

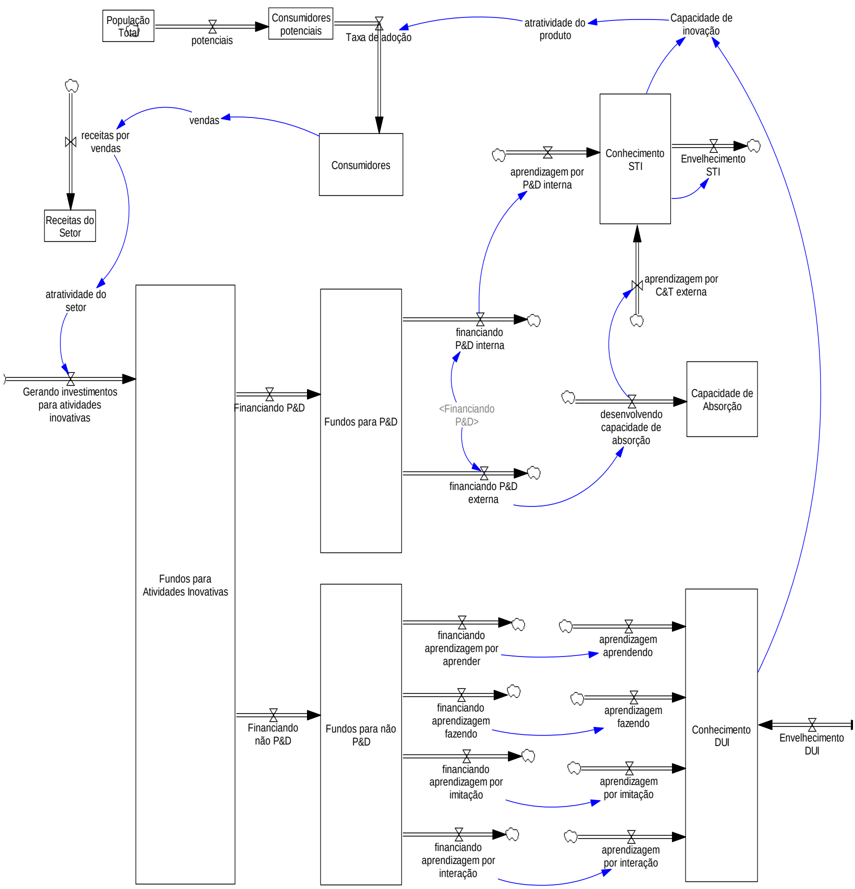
4.3 MODELO DE ESTOQUES E FLUXOS

Embora as malhas de realimentação ou *loops* identificadas no modelo CLD ajudem a esclarecer a dominância de umas malhas sobre as outras, determinando dessa forma o comportamento dinâmico do sistema, elas não servem para testar efetivamente tais dominâncias.

O modelo de estoques e fluxos ajuda a preencher essa lacuna ao gerar simulações por meio do uso do computador que visam testar a consistência das suposições geradas a partir do modelo CLD.

Para isto, o modelo de estoques e fluxos foi alimentado com dados quantitativos para determinar o comportamento passado do sistema setorial de inovação. Os dados foram coletados a partir dos relatórios disponíveis pelo Instituto Brasileiro de Geografia e Estatística (IBGE) das pesquisas sobre inovação tecnológica, PINTEC-2005 e PINTEC-2008. Uma versão simplificada do modelo de estoques e fluxos é apresentada na Figura 6.

Figura 6 – Modelo de estoques e fluxos simplificado de um sistema de inovação.



Fonte: Elaborado pelo autor.

O modelo da Figura 6 representa as ligações entre o componente financeiro, o componente científico-tecnológico, o componente produtivo-tecnológico, o componente de mercado e o componente do capital humano, considerando também as malhas de realimentação ou *loops*.

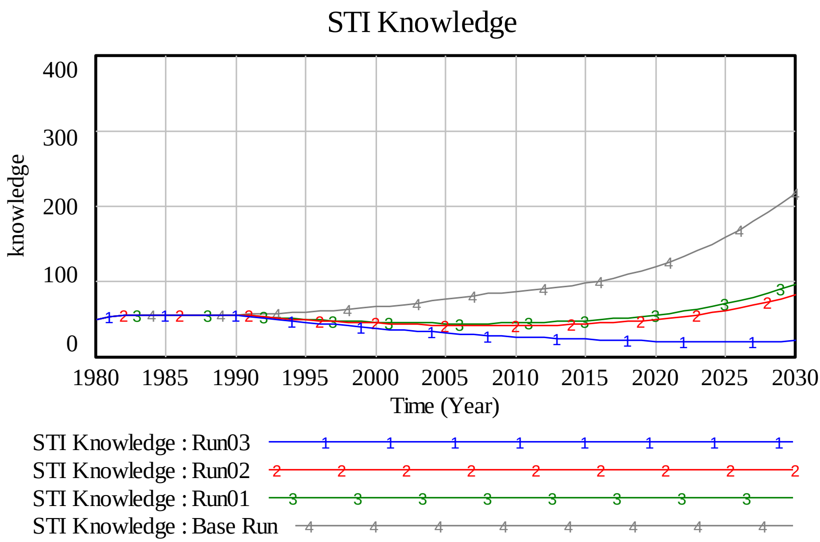
O modelo logo passou por um conjunto de provas ou testes de verificação de consistência, conforme os métodos de verificação específicos da dinâmica de sistemas. Os testes verificaram tanto a estrutura do modelo quanto o comportamento do mesmo a estímulos específicos. O modelo passou todos os testes de forma satisfatória.

4.4 EXPERIMENTOS DE SIMULAÇÃO

Por fim, os experimentos de simulação serviram para verificar a aplicabilidade do modelo de simulação. Para isto, foram realizados quatro grupos de experimentos considerando o sistema setorial de inovação de software no Brasil como ambiente de aplicação.

O primeiro experimento apresenta as diferenças na acumulação de conhecimento ao longo do tempo originadas a partir de diferentes escolhas no uso de formas de aprendizagem. Em particular a Figura 7 apresenta as diferenças entre três rodadas de simulação (Run01, Run02 e Run03) referentes a uma maior realização de atividades de P&D interna em relação a atividades de P&D externa.

Figura 7 – Experimento 01 – Conhecimento STI.



Fonte: Elaborado pelo autor.

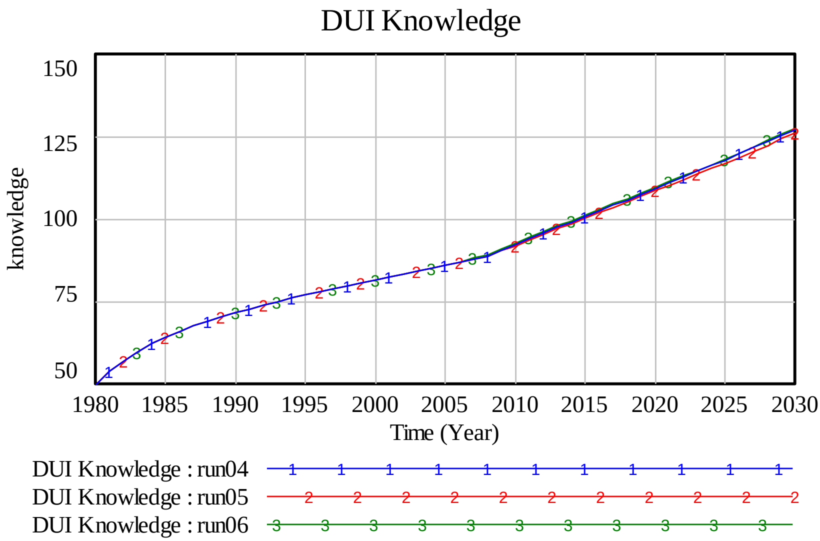
Conforme a Figura 7, a rodada Run03 é a que apresenta o pior desempenho ao longo do tempo, esta corresponde a uma realização equilibrada de atividades de P&D interna e P&D externa, ou seja, as empresas do setor de *software* realizam tanto atividades de P&D interna como compram P&D externa na mesma proporção. O desempenho pobre da rodada Run03 pode significar um uso ineficiente de recursos para atividades de P&D por parte das empresas do setor, sugerindo que seja escolhida apenas uma forma de P&D.

Os resultados das rodadas Run01 e Run02 comprovam esta conclusão, no sentido de que em ambas apresenta-se um uso mais acelerado de um tipo de P&D (neste caso de P&D interna) sobre o outro. Desta forma, os resultados deste primeiro experimento sugerem que a melhor estratégia para o sistema setorial de inovação de *software* no Brasil em termos de acumulação de conhecimento do modo STI, é a partir de um maior uso de atividades de P&D interna.

Em termos de conhecimento do tipo DUI, o experimento 01 apresenta três rodadas adicionais, considerando a importância dos clientes como fontes de conhecimento para o processo inovativo, das atividades de treinamento de pessoal e de outras fontes de conhecimento (patentes; invenções não patenteadas; licenças; *know-*

how; marcas registradas; serviços de consultoria; e acordos de transferência de tecnologia). A Figura 8 apresenta os resultados das três rodadas e seus efeitos na acumulação de conhecimento do tipo DUI.

Figura 8 – Experimento 01 – Conhecimento DUI.



Fonte: Elaborado pelo autor

Conforme a Figura 8, não existem grandes diferenças entre os três tipos de acumulação de conhecimento. Em particular, os resultados da Figura 8 sugerem que os três tipos de acumulação de conhecimento são igualmente importantes para a dinâmica inovativa do setor brasileiro de *software*, sob a ótica do conhecimento tipo DUI.

Os experimentos 2, 3 e 4 são apresentados em detalhe no Apêndice A, Seção 6.4.

5 CONCLUSÕES E RECOMENDAÇÕES

Este capítulo apresenta a versão condensada das principais conclusões e recomendações da Tese, considerando os objetivos previamente definidos, bem como os resultados obtidos.

Desta forma, a primeira conclusão do trabalho se refere à construção de um *framework* que contém os principais componentes e relações de um sistema de inovação.

O *framework* em questão apresenta-se como um esforço de sucesso em integrar um conjunto amplo de características de diversos modelos de sistemas de inovação previamente publicados numa única estrutura sistêmica. Embora pode argumentar-se que cada modelo de sistema de inovação é específico para cada estudo em particular, a possibilidade de se ter um *framework* que facilite a compreensão de como os principais componentes do sistema interagem entre sí, incrementa a capacidade de tomada de decisão sobre "qual ou quais" os modelos de sistema de inovação utilizar.

Neste sentido, conclui-se que o *framework* serviu para o propósito de oferecer um conjunto de componentes e relações comuns a todos os sistemas de inovação com o objetivo de facilitar o desenvolvimento do modelo de simulação que possa explicar a dinâmica do sistema de inovação e desta forma auxiliar na mensuração e na gestão do sistema.

O *framework*, em conjunto com o modelo CLD ajudaram a identificar os vários tipos de aprendizagem utilizados pelas empresas para criar, disseminar e usar o conhecimento na forma de produtos e processos inovadores. Neste sentido, a Tese apresentou um conjunto de malhas de realimentação ou loops que representam a dinâmica do sistema de inovação.

A tese ofereceu explicações, baseadas na descrição dos diferentes *loops* e na interação entre eles, sobre os principais mecanismos de geração de atividades inovativas. Conclui-se, portanto que esses mecanismos estão relacionados com as diferentes formas de aprendizagem, para a acumulação de conhecimento STI e DUI, que as empresas escolhem.

Por sua vez, essa escolha depende de diferentes estímulos externos ao sistema e também das diferentes interações entre as malhas de realimentação. Assim, as mudanças na política pública e mais especificamente nas políticas de ciência, tecnologia e inovação afetam as decisões das empresas do setor de *software*, quando da escolha dos mecanismos utilizados para a atividade inovativa.

Por fim, o modelo de estoques e fluxos ofereceu a capacidade de simular o comportamento do setor de *software* de Brasil a mudanças em diferentes parâmetros relacionados com o regime tecnológico do setor. O modelo de simulação utilizou dados quantitativos da PINTEC-2005 e PINTEC-2008, a partir dos quais elaboraram-se relações matemáticas entre as variáveis do sistema setorial.

As relações matemáticas foram elaboradas também a partir da parametrização de dados qualitativos obtidos a partir da revisão de literatura sobre o setor de *software*. Por tanto, essas relações podem ser melhor definidas em futuros trabalhos a partir de novas fontes de dados quantitativos, ajudando com uma melhor parametrização de valores críticos para o modelo.

Recomenda-se portanto para futuros trabalhos realizar um levantamento de dados quantitativos que vise complementar o trabalho feito nesta Tese.

Em termos do *framework*, uma inclusão de bases de dados científicas adicionais às levadas em consideração nesta Tese, pode ajudar a validar a escolha dos componentes e relações utilizados ou inclusive a modificar, adicionar ou exclui-los, com base nos novos resultados.

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APÊNDICE A – Dynamics of Sectoral Systems

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1

Introduction

Innovation through the creation, diffusion and use of knowledge has become a key driver of economic growth in organizations, regions and countries (OECD, 2001; Lugones, 2012). It is arguably accepted that firms do not innovate in isolation but in continuous and complex interactions with other sources of knowledge at the local, national and international levels among several actors (Chaminade, 2001; OECD, 2001).

This has been the argument used by scholars since Schumpeter (1961), to Nelson and Winter (1982), and Nonaka and Takeuchi (1995) among others, and specifically in the systemic approach of technical change, known as the Innovation System approach.

Since the 1980s, the Innovation Systems approach has provided a framework to explain the complex interactions between the institutional actors that participate on the innovation process. With the seminal contributions of Freeman (1987), Lundvall (1992) and Nelson (1993), the Innovation Systems approach has attracted the attention of many innovation researchers and policy makers and has achieved broad international diffusion in both developed and developing countries (Edquist and Hommen, 2008).

Rooted on the evolutionary and institutional economics streams, bounded rationality, and the thermodynamic theory of open systems (Niosi and Bellon, 1994), the innovation systems approach has derived to different levels of analysis, the national level (Freeman, 1987; Lundvall, 1992; Nelson, 1993), regional level (Cooke et al., 1997), the sectoral level (Malerba, 2002) and the technological level (Bergek et al., 2008).

As recent literature suggests, innovation systems are complex systems, because they are subject to continuous change and evolution (Niosi, 2011).

Such dynamic conditions produce no optimal policies, because the internal endogenous structure of the innovation system resists to adaptation (Liu and White, 2001), and often cause unintended and unpredictable effects. In this sense, a better look at the structure of the innovation system might help in identifying the key determinants and the causal links that resist to change and adaptation, in order to improve the efficiency and effectiveness of the system.

However, as Edquist and Hommen (2008) have suggested, such a work is a surprisingly under-researched area in innovation studies, because of the difficulty in identifying causal internal explanations to the propensity to innovate. Thus, a sectoral innovation system approach might help in looking at the relationships between sector-specific and context-specific actors, policies and innovative activities within a particular internal structure (Malerba, 2002).

Sectors play an important role in directing technological trajectories and supporting innovation within countries because sectors are suitable environments for the flow of knowledge within the system. The advantage of using a sectoral systems lens is that firms and other agents within a sector often share a common knowledge base and common institutions and organizations, which help in identifying key internal determinants components and linkages that affect the system behavior.

By focusing this dissertation on a particular sector, the importance of knowledge and learning processes within the internal structure of the innovation system as well as the role of firms and other organizations, institutions and policies in supporting and directing these processes may be explored in an easier way as well as the complex dynamic behavior that is produced by the system. The sector I chose is one that corresponds to the so-called Knowledge-intensive Business Service Sectors (KIBS), which are defined as services that create, accumulate or disseminate knowledge extensively in order to deliver their products (Muller and Doloreux, 2009). More specifically, the sector studied is the Software Sector in Brazil, which has gained considerable attention in recent years (Roselino, 2006; Britto and Stallivieri, 2010; Diegues and Roselino, 2011).

The Software Sector in Brazil presents many challenges, making it an interesting subject of study from a complex systems perspective and from a sectoral innovation systems approach. In order to identify the key structures and mechanisms that are specific to this sector, I develop a formal model, composed by a modeling framework and a system dynamics model.

The modeling framework fills a gap related to the lack of previous studies incorporating the key components and linkages of an innovation system into a single representation. The modeling framework is built from a comprehensive review of the literature procedure, known as a systematic review.

The System Dynamics model aims at integrating the components and linkages identified in the previous framework into an explicit dynamic simulation model. The SD model is designed to investigate how the different parts or components of the system are linked, how they produce the behavior of the entire system and how alternative policies might yield more efficient and effective results.

The model can be particularly useful to understand how knowledge and learning processes can affect the behavior of the Brazilian software sectoral system, due to the interaction of financial, human, information and knowledge flows. In addition, this model can allow comparative analyses between several alternative policies, the evolutionary and co-evolutionary processes taking place within the system, the role of specific institutional settings and ultimately, the benefit of both scholars and policy makers in Brazil and elsewhere[1].

1.1 Research Problem

As discussed earlier, the innovation systems approach has widely diffused across developed and developing countries, as well as across supranational institutions such as Organization for Economic Co-operation and Development (OECD), World Bank (WB), and the International Monetary Fund (IMF) among others, by successfully emphasizing the role of science, technology and innovation (STI) institutions, placing it, according to Niosi (2011), at the center of theoretical and policy debates on economic development.

Accordingly, reports such as the Global Competitiveness Index from the World Bank (Schwab, 2010) and the Global Innovation Index from INSEAD (2010) have shown that countries with effective and efficient innovation systems have also a higher economic development, among others,

[1]The author wishes to thank many scholars whom have contributed with their comments in developing this Dissertation: A. Phadtare (Duke U), B.A. Lundvall (Aalborg U), C. Murcia (UAM), E. Bueno (UAM), F. Malerba (Bocconi U), GRINEI Research Group (Complutense U), H. Morero (Cordoba U), I. Alvarez (Complutense U), J. Shah (Duke U), J. Sterman (MIT), J. Niosi (UQAM), J. Morecroft (London Business School), J.M. Natera (Complutense U), J.W. Forrester (MIT), L. Lee (Kaohsiung U), PhD Colloquium of the System Dynamics Society Korea/2010, PhD Colloquium of the System Dynamics Society USA/2011, PhD Globelics Academy Finland/2011, P. Bittencourt (UFSC), R. Pietrobon (Duke U) and many others and throughout the whole PhD process, colleagues and friends from NGS/UFSC, G. Varvakis, R. Pacheco and V. Kern

the United States, the United Kingdom, Finland, Germany and Sweden.

However, the efficiency and effectiveness of an innovation system depends of changes in different flows, especially of knowledge flows (Niosi, 2002; OECD, 2002) but also of information, financial capital and human capital flows. Most of current literature on innovation systems has focused on the static nature of the system (stocks of knowledge, money and people), on the other hand, little attention has been given to the flows and its rates which are the vectors of change[2] in the system, i.e. dynamics, within an innovation system, are governed by changes in flow rates: flows of knowledge, information, financial capital and human capital.

Changes in flow rates confer innovation systems the nature of complex dynamic systems, systems in which strong and dispersed interactions among heterogeneous agents and co-evolutionary processes takes place (Niosi, 2011). Thus, as many other complex systems, policies which were meant to increase the performance of the innovation system often produce the opposite, unintended effect, caused, as Liu and White (2001) suggest, by the innovation system inherently endogenous structure. As Lundvall emphasized a system of innovationsis also a dynamic system, characterized both by positive feedback and by reproductioncumulative causation, and virtuous and vicious circles, are characteristics of systems and sub-systems of innovation (Lundvall, 1992).

Moreover, the literature on innovation systems has not reached consensus on many aspects related to the approach, from its own definition per se to the use of key terms in ambiguous ways (Niosi, 2002; Edquist and Hommen, 2008), producing theoretical and practical gaps.

From a theoretical perspective, there is a lack of studies related to understand how knowledge flows throughout the system; moreover, there is not a consensus in the literature on the main components and linkages of the innovation system; there are only a few studies which have worked on the dynamic nature and behavior of innovation systems (Carlsson et al., 2002; Lee, 2002; Lee and Yoo, 2007; Godin, 2009).

From a practical or policy making perspective, the current tools, techniques and methods used to analyze innovation systems are limited by their inability to take into account nonlinear interactions, and complex dynamic behavior of the different flows in the system (Lyneis, 2000; van Raan, 2003; Atkinson and Andes, 2009). On one hand, statistical and econometric approaches are based on the premise that future behavior depends solely on past behavior, without considering the internal interactions on the system. Statistical approaches have not done a good job in explaining the complexity of nonlinear, dynamic systems because they do not account

[2]Vectors in the sense that they contain a magnitude, a direction and a polarity

for capturing the structure of the system which creates behavior over time (Lyneis, 2000).

On the other hand, expert-based opinion are influenced by subjective elements, limited knowledge and narrowness in mental models combined with respondent biases, resulting likely in a reflection of the reputation of the system rather than its actual state and since it lacks of a hard quantitative basis for sustaining their proposal, they may also fail in explaining the behavior changes over time (van Raan, 2003).

In this sense, a better look at the dynamic structure of the innovation system might help in identifying the key determinants and the causal links that resist to change and adaptation, in order to improve the efficiency and effectiveness of the system. Thus, the main research question is:

How do knowledge and learning processes affect the dynamics of innovative activity?

Since this dissertation is theoretically grounded on the Innovation System approach, and specifically on the Sectoral Innovation System, the Software Sector in Brazil is conceived as a system in which the following specific research questions are relevant:

- What roles do knowledge and learning flows play in the innovative activity?

- How does their interaction produce changes in the behavior of the entire sectoral system?

- How do alternative policies might yield to better performance?

1.2 Research Objectives

According to what has been discussed in previous sections, sectoral innovation systems consist of knowledge flows representing the linkages among the system's actors and stocks, which every actor aims at increasing by means of learning. Each sectoral innovation system is in essence a complex adaptive system, which implies that differences in the structuring of such complex systems create different innovative performance.

In this sense, the main objective of this dissertation is to improve the understanding of how knowledge and learning processes affect the dynamics of innovative activities, within an innovation systems perspective.

Specific Objectives:

1. To identify the main components and linkages of an innovation system
2. To synthesize the main components and linkages into a modeling framework
3. To design a simulation model, based on the modelling framework and instantiate it to the case of the Software Sector in Brazil
4. To run simulation experiments testing the effects of knowledge and learning processes on the dynamics of the software sectoral system in Brazil

1.3 Materials and Methods

In order to fulfill the previously described objectives, this dissertation uses a mixed methods approach, composed of a systematic review of the literature and a system dynamics modelling. Since the current literature of innovation systems offers a wide variety of models made of components and linkages from conceptual to mathematical ones, before using a dynamic modeling approach to represent the sectoral system in study, it is necessary to come up with a specific modeling framework.

The modeling framework of this dissertation was based on an extensive review of the literature, based on the systematic review (SR) method. The difference between a traditional literature review and a systematic one, is that the latter offers a reproducible procedure which is made explicit throughout the review process, providing transparency to the selection of critical literature used to design the modeling framework (Khan et al., 2001; Petticrew and Roberts, 2006; Crossan and Apaydin, 2010).

The modeling framework offers a higher confidence level because it is based on previous literature published on scientifically renowned sources. In addition, the elements and linkages identified in the literature and included in the modeling framework offer a high degree of applicability to innovation systems models in general because of its abstraction level.

After the previous models in the literature were analyzed through the SR process, a System Dynamics model was built based upon Sterman (2000) and Morecroft (2007) methods. System Dynamics helps in understanding patterns of behavior on complex systems in a more rigorous, scientific and consistent fashion by identifying the key-elements of dynamic complexity: time lags/delays, feedback loops and stocks and flows (Forrester, 1989b; Lyneis, 2000; Sterman, 2000).

System Dynamics enable the modeling of complex nonlinear social systems by describing the causal explanations that produce their performance and behavior through causal loop diagrams (CLD) and by proposing alternative policies through rigorous modeling and simulation methods (Forrester, 1994; Sterman, 2000). Both approaches were used aiming at improving the understanding of the dynamics within the sectoral system of the Brazilian Software Sector.

The dynamic model was then tested against behavioral and structural validity tests (Forrester and Senge, 1980). Parameter estimation was based on data from the PINTEC dataset the Industrial Research on Technological Innovation, conducted by IBGEBrazilian Institute of Statistics and Geography. PINTEC was designed following the recommendations of the Oslo Manual and on the European Community Innovation Surveys (CIS), which has given it broad credibility, comparability and broad applicability in sectoral studies (Kannebley et al., 2005; OECD, 2005; IBGE, 2010).

The PINTEC survey is the most comprehensive source on product and process innovations from an official entity in Brazil. The two latest datasets from PINTEC were used: PINTEC-2005 and PINTEC-2008[3] . The PINTEC-2005 sample size for software firms was 3.811 firms and the PINTEC-2008 sample size for software firms was 2.514 firms.

Finally, simulation experiments were conducted in order to observe the changes in the dynamics of the Brazilian Software Sectoral Innovation System by testing explicit assumptions related to knowledge and learning activities: technological opportunities, properties of the knowledge base, appropriability conditions and cumulativeness conditions which entail changes in the rates and levels of knowledge and learning processes.

1.4 Structure of the Dissertation

This dissertation is structured in seven chapters, including this one. The remaining chapters are structured as follows:

Chapter 2 Literature Review on Innovation Systems, describes the innovation systems approach, which is the main conceptual and theoretical framework of this dissertation.

Chapter 3 System Dynamics, introduces the theoretical and methodological base of System Dynamics and also, the dynamic patterns and interaction structures of complex systems.

[3] Two subcategories from PINTEC-2005 and PINTEC-2008 were used as proxies of the Software Sector in Brazil.

Chapter 4 Research Method, introduces the research method and procedures used to fulfill the objectives of this dissertation.

Chapter 5 Modeling Framework and Causal Loop Model Design, describes the design of a modeling framework, which is composed by the main components and linkages of an innovation system and presents the main feedback structures and causal loops of an innovation system.

Chapter 6 System Dynamics Model Design and Simulation Experiments, instantiates the modeling framework for the case of the Software Sector, by using a sectoral innovation systems approach, presents the formalization of the system dynamics model and concludes with the several simulation experiments aimed at testing the dynamic behavior of the system in study.

Chapter 7 Conclusions and Future Work, presents the main conclusions of the study and the main recommendations for future work.

2

A Literature Review on Innovation Systems

> Economists have, by and large, analysed technological innovation as a "black box" - a system containing unknown components and processes. They have attempted to identify and measure the main inputs that enter that black box, and they have, with much greater difficulty, attempted to identify and measure the output emanating from that box. However, they have devoted little attention to what actually goes inside the box; they have largely neglected the highly complex processes through which certain inputs are transformed into certain outputs (in this case, new technologies). Kline and Rosenberg (1986)

In the past decades, specialized literature on Science, Technology and Innovation has been interested in "opening up" the black box mentioned by Kline and Rosenberg (1986). Traditional work on this subject suggests that there has been an "evolutionary process" of explanations on how and why knowledge is transformed into innovative goods and services, which has produced several theoretical or conceptual approaches, one of this approaches is the Innovation Systems (IS) or Systems of innovation (SI) conceptual framework (Kern et al., 2011).

This chapter has as objective to introduce the IS approach, which is the main conceptual and theoretical framework of this dissertation. Thus, a review of innovation models and approaches is initially presented, followed by the most relevant theoretical base of IS literature. The chapter then takes a deeper analysis on the sectoral innovation systems (SIS) approach, and concludes with the major strengths and weaknesses of the approach.

2.1 Knowledge, learning and innovation

Knowledge and learning are not distributed evenly throughout the firm (Nissen, 2006), thus neither innovation, considered to be the outcome of knowledge flows and learning processes (Lundvall, 1998).

All three concepts lie on a metaphor that considers organizations "learn" as humans do, and that therefore, they create, acquire, store, share and use knowledge throughout their activities. At the same time, knowledge and learning within the firm and between the firm and other agents, is mainly directed to the production of new or improved products and processes.

Allegedly, innovation has been defined as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD, 2005).

In this sense, the management of knowledge turns out the means to which innovative activities occur, in which the firm "learns" by performing R&D activities, training activities, hiring activities and by using the previously stored knowledge, through interactions among several agents (Lastres et al., 2003; Cassiolato and Lastres, 2008). Moreover, specialized literature has suggested that learning activities can be characterized as inflows through which knowledge is created and stored in the form of a knowledge stock the level of accumulated knowledge over a period of time (Bontis et al., 2002; Vera and Crossan, 2003).

Thus, it can be concluded that:

$$innovation(t) = f(knowledge(t-1)) \tag{2.1}$$

$$knowledgestock(t) = f(learning_i(t-1)) \tag{2.2}$$

Where i = different learning types

In addition, innovation activities are especially important for knowledge-intensive business services (KIBS), which are defined as services that create, accumulate or disseminate knowledge extensively in order to deliver their products (Muller and Doloreux, 2009); these are firms that use knowledge as its major asset in order to produce high-technology services.

KIBS serve as sources of innovation when they develop processes or deliver services; serve as facilitators when they support other organizations in their innovation processes; and also, serve as carriers of innovation when they participate in technology-transfer activities (OECD, 2006).

2.2 Traditional approaches explaining innovation

This section reviews the main traditional models and approaches that had been proposed by the literature that received more acceptance by scholars and policy-makers throughout the years, in search for a common ground to start the analysis of IS in general and SIS in particular.

The first traditional innovation model dates back to the 1940‘s. After the World War II had finished, the Unites States developed stronger policies promoting science and R&D within their public agencies, institutions and also within private industry. According to scholarly literature, Vannevar Bush's report "Science: The endless frontier" was one of the most important drivers for the United States to direct their federal funds to universities, which in turn would produce academic research and new generations of scientists and engineers (Lane, 2008). The knowledge produced through R&D would then be transformed into products with commercial value and offered to the market by private firms.

By the 1950‘s, the majority of industrialized countries had already adopted this model, which assumed that "more R&D" resulted in "more product innovation", making it easier for governments to formulate R&D oriented policies (Viotti, 2003). This model came to be known as the "linear technology-push model" and is depicted in Figure 2.1.

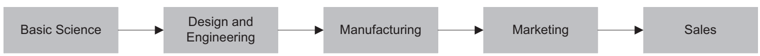

Figure 2.1: **Linear Technology-Push Model.** - Source: Rothwell (1994)

According to Figure 2.1, there exists a direct relationship between basic research, design and engineering, product manufacturing, marketing and finally lending to sales and commercialization (Rothwell, 1994). Basic research is primarily done by universities and research institutions which transfer their knowledge to firms. Firms then, design and produce the products and send them to the market. Markets in this sense do not appear as relevant actors in the innovation process but as merely receivers of the results of R&D (Hobday, 2005).

The second generation of linear innovation models was adopted by several countries in the early-to-mid-1960's which perceived innovations derived from market demands. The demand-pull or market-pull approach (See Figure 2.2) sees consumer and market needs as the start point for innovation, R&D then, has a reactive role and follows the directions stated by the markets (Hobday, 2005; Velasco and Zamanillo, 2008).

Figure 2.2: **Linear Market-Pull Model** - Source: Rothwell (1994)

In the forthcoming years, Linear Models were mainly criticized for being purely sequential leaving no space for cyclic process of information feedback and forward (Viotti, 2003). Mowery and Rosenberg (1979) among others, sustained that the technology-push and market-pull models were only atypical examples of a rather more complex interaction process between technological capability and market needs. As a response, a new generation of innovation models was introduced in the 1970's, which could be regarded as a set of logically sequential processes but with feedback loops, illustrated in Figure 2.3 (Rothwell, 1994).

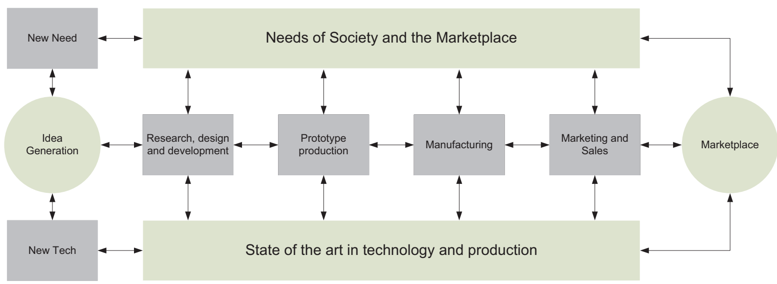

Figure 2.3: **The coupling model** - Source: Rothwell (1994)

According to Hobday (2005), the main advantage of the coupling model in relation to the linear models was that it explicitly linked decision making in firms with the Science and Technology community and with the marketplace.

Short after, the next generation of innovation models focused on the integration and parallel development, rather than on linearly sequential processes. They started in the 1980's, and they state that innovation occurs where concurrent or even simultaneous processes take place (Rothwell, 1994), under these generation the Chain Linked Model (CLM) was proposed. CLM is illustrated in Figure 2.4 and presents five trajectories involving complex iterations and several feedback loops between different stages of the Central Chain of Innovation (CCI), R&D and Scientific and Technical Knowledge (Kline and Rosenberg, 1986).

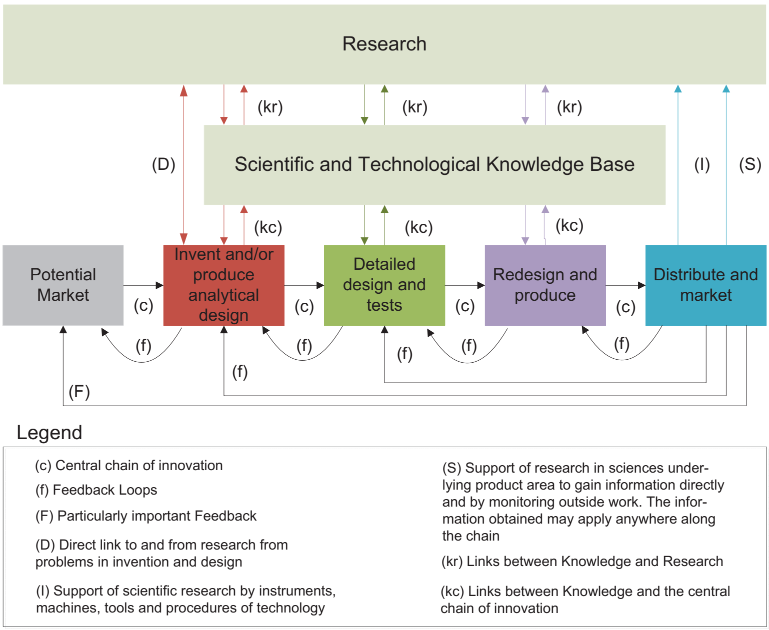

Figure 2.4: **The Chain-linked Model** - Source: Kline and Rosenberg (1986)

According to Figure 2.4, there are different flows among the components of the CLM. The first type of links is the so-called "Central Chain of Innovations - CCI" depicted with the (c) arrows. CCI resembles a linear market-pull model with feedback loops depicted by (f) arrows and the major feedback loop (F) between the market and the potential market. Simultaneously, different stages of the CCI interact with the Knowledge Base and in turn with the Research base. Some special links are (D), the relationship between problems in invention and design with Research; and (I) and (S), support of research by instruments, machines, tools, procedures, for the first, and support of research by sciences, for the latter.

The CLM offers additional explanations on how the innovation process takes place, in the sense it shows the interconnectedness embedded on the process and more importantly, the feedback loops between the process and the larger system in which it operates.

The next generation of innovation models, considers an even wider perspective, in line with the relationship between innovation processes taken place on firms and the larger system they are embedded on. According to Viotti (2003), this type of models consider the systemic nature of innovation, which includes the firms as innovation agents but also several other institutional agents that influence on the process: universities, research institutes, government agencies, etc.

The model is known as the systemic model, based theoretically on the innovation systems approach, which was initially proposed for the national level, arguing that it was the national institutional set-up that helped in defining innovative activities of firms through several mechanisms (government regulations, industrial policy, university-industry linkages, etc.). The model came to be known as the National Innovation System (NIS) model. The OECD proposed a diagram for a generic NIS which meant to help in understanding how the components of the NIS are interrelated, shown in Figure 2.5 (OECD, 1999).

The OECD's generic model instantiates different possible actors and relationships in a NIS. As Edquist (2005) points out, there is a general agreement that firms are considered to be the most important organizations for innovation, therefore, appearing at the heart of the model; other important institutions are research and science ones and other supporting institutions, such as government agencies or NGOs.

Notwithstanding, many of the components and relationships of national systems and of innovation systems in general are seldom known entirely, which does not endanger the validity of the approach, in fact, it would be unrealistic to specify all of those due to their number and complexity. Edquist (2005) in this sense, points out that the purpose of using the national innovation systems approach is to generate incremental knowledge about the system as new hypotheses are proposed about the relations between specific variables.

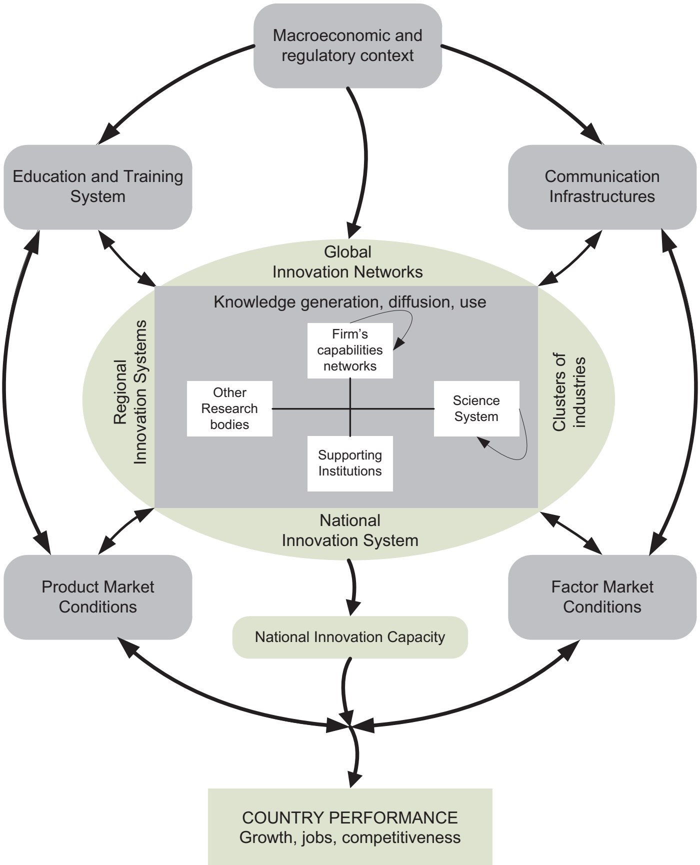

Figure 2.5: **The OECD National Innovation Systems Model** - Source: OECD (1999)

2.3 The innovation systems approach

Overall development the improvement of economic, social and technological conditions of a society is one of the most relevant themes in public policy in a large number of countries and regions all over the world.

Accordingly, when economists such as J. Schumpeter evidenced the importance of innovation as a driver for economic development, the field became the center of attention for policy makers and innovation scholars (Schumpeter, 1961). Figure 2.6 shows the evolution of research related to innovation and economic development from the 18th Century to today.

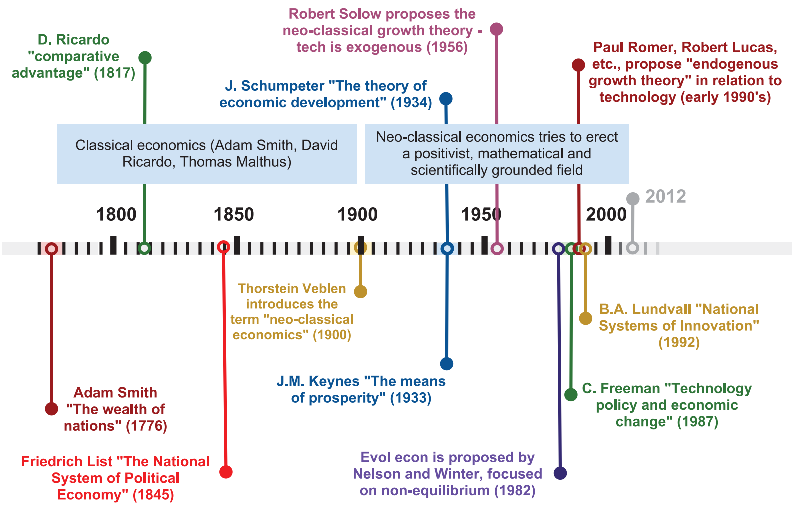

Figure 2.6: **Timeline of the evolution of innovation and economic development research** - Source: Author

As Figure 2.6 shows, several theoretical streams influenced in smaller and/or larger proportions the evolution of the Innovation Systems (IS) approach. Originally proposed in the 1980's by scholars interested in building up an alternative approach to the neoclassical approach, the innovation systems framework was set to explain how economic development was accomplished by diverse developed countries and how it could be used as a policy tool to accomplish similar outcomes in less-developed ones. It is not clear which of those scholars was actually the first one to propose the innovation systems framework, however, it is known that somehow they managed to influence to each other in order to bring up the version it is used nowadays, those scholars were Richard Nelson, Chris Freeman and Bengt Ake Lundvall.

As previously stated, Freeman (1987), Lundvall (1992) and Nelson (1993) are known to be the creators of the approach. Although, there is no certainty on which one of them was actually the first proposer, all three shared important common foundations: 1) the need to embrace other agents rather than pure economic ones; 2) the complex interactions between institutional actors, processes and structures inside a geographical context, mainly national context and 3) the importance of scientific and technological knowledge to produce innovations.

In a nutshell, in 1987 C. Freeman wrote the book "Technology policy and economic performance: lessons from Japan" where he discussed how technology policy helped Japan in becoming an economic power, and highlighted the importance of the complex linkages among different institutional agents on the success of those policies (Freeman, 1987). In 1988, G. Dosi, C. Freeman, R. Nelson, G. Silverberg e L. Soete edited a book entitled "Technical Change and Economic Theory" (Dosi et al., 1988) which accounted with a specific section devoted to the discussion of National Innovation Systems including the work of Nelson (1988), Freeman (1988) and Lundvall (1988). Was B.A. Lundvall that in 1992 wrote another important book, entitled "National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning" where he discussed about the IS approach in different settings (Lundvall, 1992). And one year later, R. Nelson wrote "National Innovation Systems: A Comparative Analysis" where he compared and examined the National Innovation Systems of fifteen different countries (Nelson, 1993). Soon after those books were published, many other scholars embraced the innovation systems approach and contributed with their own views. Among them, in 1998, Bracyk and Cooke published a book entitled "Regional Innovation Systems: The Role of Governances in a Globalized World" where the authors discussed the role of other geographical contexts besides the national one (Braczyk et al., 1998). P. Cooke specially, had been working with the role of the regional context for innovation systems since the 1990s and has published many scholarly works since then (Cooke, 1992; Cooke et al., 1997, 1998). J. Niosi has also contributed in the study of regional systems and national systems and to some extent, on high-tech industries such as biotechnology and software e.g. (Niosi et al., 1993; Niosi and Tschang, 2009).

Another stream that emerged during the following years to the appearing of the National Innovation System approach, was the Sectoral approach. In this approach, the proposing authors were interested in the notion that for some IS, the industrial sector is more important than geographical borders, given that some sectors outbound them. Scholars such as F. Malerba gave birth to this stream and thus, published many works on these subject (Malerba, 2002).

Another important stream that outflowed from the original version was the technological systems of innovation approach, that proposed to look for technology-driven knowledge flows on the system rather than geographical or sectoral set-ups (Carlsson and Stankiewicz, 1991; Carlsson et al., 2002). The technological approach outbounds geographical borders as well as sectoral borders, i.e. a specific technology might be used in different industrial sectors.

In addition to the blossoming of sub-types of Innovation Systems as discussed above, the innovation systems approach has also been linked to similar frameworks and theories. It is the case of the Triple Helix framework, which particularly states the relationship between three actors: universities, firms and government (Etzkowitz and Leydesdorff, 2000). For innovation systems scholars, the Triple Helix represents one of its many sub-systems, because an innovation systems entails additional relationships with other actors (Uriona Maldonado et al., 2012). In this sense, an innovation system is composed by components, relationship and attributes (Carlsson et al., 2002; Edquist, 2005).

The components are "the operating parts of the system" and for Edquist innovation systems account for two basic types of components which are organizations and institutions (Carlsson et al., 2002; Edquist, 2005). "Organizations are formal structures that are consciously created and have an explicit purpose". Accordingly, examples of Organizations are: firms, universities, venture capital organizations and public agencies responsible for innovation policy; they can also be named as actors (Edquist, 2005).

Institutions on the other hand, are "sets of common habits, norms, routines, established practices, rules or laws that regulate the relations and interactions between individuals, groups and organizations". Examples of Institutions might be: patent laws as well as rules and norms influencing the relations between universities and firms or traditions and social norms (Carlsson et al., 2002; Edquist, 2005).

The second element of an innovation system, are the "relationships" or "linkages", which are the links between the components. These links represent the dependency of each component upon the properties and behavior of at least one other component of the system (Carlsson et al., 2002). As Carlsson et al. (2002) explains, these relationships produce feedback mechanisms that make an "innovation system" to be dynamic, in other words, by enhancing the interactions among the components, the system will be more dynamic. As a result of the feedback mechanisms among the components and mainly the actors, their properties may change over time and therefore the whole configuration of the innovation system.

The third element is known as "attributes", which are the "properties of the components and the relationships between them" (Carlsson et al., 2002). They are related to the function or purpose of the system, so if an innovation system's purpose is "to develop, diffuse and use innovations" (Edquist, 2005), then the attributes would be the capabilities of the actors to develop, diffuse and use innovations.

Since the early 1980's and especially during the last decade, the use of the innovation systems approach has increased in both academic and policy-making fields. Organizations such as the Organization for Economic Cooperation and Development (OECD), the United Nations Conference on Trade and Development (UNCTAD), the World Bank and the International Monetary Fund (IMF) use the approach to inform policy-making and to conduct research on regional and national contexts (OECD, 1997; Sharif, 2006).

On the academic side, as a sample of the recent studies using the IS approach, Lee and Yoo (2007) have analyzed the national innovation systems of France and South Korea; Edgington (2008) who has studied the Japanese innovation system and the OECD which has conducted studies on the national innovation systems of China and South Korea (OECD, 2009b,a).

2.4 Sectoral Innovation Systems

As discussed before, the sectoral innovation systems approach is a subset of the innovation systems literature. Although it shares a common theoretical basis, the sectoral approach emphasizes some aspects that are important for the study of innovation and specifically for the aims of this dissertation.

First, the notion of sector, which is a set of economic activities that are unified by a group of products linked to a given or emerging demand, and which share a common knowledge. Thus, a sectoral system of innovation is "a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products" (Malerba, 2002).

Second, sectors play an important role in directing technological trajectories and supporting innovation within countries because sectors are suitable environments for observing the flow of knowledge within systems that share common elements. The advantage of using a sectoral systems lens is that firms and other agents within a sector often share a common knowledge base and common institutions and organizations, which help in identifying key internal determinants components and linkages that affect the system behavior.

Third, the sectoral innovation system approach highlights that most economic and innovative change takes place at the sectoral level and therefore it is an adequate context to study economic and technical change at different levels. In this sense, the sectoral approach as well as the innovation systems approach is based on the evolutionary and institutional economics streams, bounded rationality, and the thermodynamic theory of open systems (Niosi and Bellon, 1994), where evolutionary theory places key emphasis on dynamics, innovation processes, and economic transformation (Nelson and Winter, 1982; Malerba and Nelson, 2011).

Fourth, the sectoral approach focuses on learning process as the main mechanisms used by actors to create, use and store knowledge. Thus, different sectors may have different ways to learn and different capacity building schemes, i.e. learning by doing, learning by interacting and so on. And fifth, by focusing this dissertation on a particular sector, the importance of knowledge and learning processes within the internal structure of the innovation system as well as the role of firms and other organizations, institutions and policies in supporting and directing these processes may be explored in an easier way as well as the complex dynamic behavior that is produced by the system.

Franco Malerba, the main author of this theoretical stream, states that the sectoral approach focuses on the nature, structure, organization and dynamics of innovative and productive activity in sectors, therefore, it comprises three dimensions: actors and networks, a common knowledge base; and institutions (Malerba, 2002).

2.4.1 The elements of Sectoral Innovation Systems

First, any innovation system is composed of actors, which are universities, research centers, firms, government agencies and the training and education system (Niosi, 2010). Sectoral innovation systems focus on a more manageable group of them since they all have to be related to a specific sector in the economy.

Actors within sectoral innovation systems are linked by different types of interactions, conforming networks and characterized by different types of flows: financial flows between government and private organizations, human flows between universities, firms, and government labs, regulation flows emanating from government agencies towards firms, and knowledge flows among all of them (Malerba, 2002; Niosi, 2002). Usually, business firms are acknowledged to be the central actors within the innovation systems and economic development literature, and learning as the key driver of technological catch-up (Malerba and Nelson, 2011) however, other actors are also extremely important, among them, the vertical linkages with suppliers and customers are sources of learning and knowledge (Jensen et al., 2007); universities and research centers, which provide scientific and technological knowledge (Niosi, 2010); financial organizations, such as public funding agencies or financial banks (Unger and Zagler, 2003) and the qualified labor market (Castellacci, 2007).

Second, all actors within a sectoral innovation system share a common base of knowledge, that is, a specific set of materials, technologies and knowledge that are used to perform innovative activities. Depending on the sector, the knowledge base may be highly tacit and hard to transfer across the firm‘s boundaries to other firms, in contrast for other sectors it may be highly explicit and easier to transfer. Therefore, sectors differ greatly in the way their firms "learn", this is, in the way firms create and acquire knowledge, some sectors may be more R&D intensive, others may be more involved in acquiring external knowledge through the investments in new types of equipment and instrumentation created by firms outside the sector and so on (Malerba and Nelson, 2011).

Third, the sectoral innovation system is focused on specific institutions, which are defined as the norms, routines, common habits, established practices, rules, etc. that shape firm‘s behavior (Malerba, 2002).

Institutions are the more complex and abstract elements of sectoral systems, since they may include the ones that bind or impose enforcements on agents to ones that are created by interactions among agents (such as contracts), formal and informal (such as patent laws or specific regulations versus traditions and conventions); national (such as the patent system) or sector-specific (such as sectoral labor markets or financial institutions) (Malerba and Nelson, 2011)

2.4.2 Technological Regimes

Besides the elements that compose a sectoral innovation system, there are framework conditions, which are specific to each sector and that influence on the innovative behavior of the whole system, they are known in the literature as technological regimes. Along with similar concepts found in the literature, such as technological paradigms (Dosi, 1982), natural trajectories (Nelson and Winter, 1982) and sectoral patterns of technical change (Pavitt, 1984) among many others, technological regimes try to explain changes in the behavior of an industry due to specific conditions that shape that industry.

In this sense, a technological regime is the environment in which firm‘s innovative activities takes place, and is shaped by four conditions: nature of the knowledge base, technological opportunities, appropriability conditions, and cumulativeness conditions (Nelson and Winter, 1982; Castellacci, 2007).

Nature of the knowledge base

Knowledge plays a central role in innovative activities and is accumulated by different types of learning and capabilities (Malerba and Nelson, 2011) and different learning rates also affect the way firms accumulate knowledge, and therefore the overall dynamics of the sectoral system. However, knowledge can be characterized as multi-dimensional, since it can be explicit and tacit (Nonaka and Takeuchi, 1995), science and technology-oriented and doing-using-interacting oriented (Jensen et al., 2007), know what', 'know why', 'know how' and 'know who' (Johnson et al., 2002) and many other forms.

In this sense, the nature of the knowledge base is a determinant of how knowledge will flow throughout the system and thus how it will impact on the innovative capability of the sector.

Technological Opportunities

Technologically advanced sectors have been traditionally linked with high levels of opportunity conditions. Moreover, such conditions are believed to be positively correlated with the rate of performance improvement over time (Castellacci, 2007). However, literature has also suggested that high levels of technological opportunities are not constant, i.e. high opportunity levels may be related to the early stages of a sector, while, low opportunity levels, related to later stages in the development of the same sector (Malerba and Orsenigo, 1993). Literature has also suggested that opportunities are built through three sources: advances in scientific knowledge, technological advances in other industries (spillovers), and positive feedbacks from the sector‘s own technological advance (Klevorick et al., 1995).

Advances in scientific knowledge may be related to STI-mode of knowledge (Jensen et al., 2007), in which scientific and technological knowledge may come from external sources. On the other hand, technological advances in other industries may be related to external knowledge acquisition of DUI-mode (Jensen et al., 2007), in which firms search for technological solutions to their problems in their vertical and horizontal chains. Finally, positive feedback from the industry itself are related to the reinforcing loops existing within the industry

Appropriability Conditions

Appropriability conditions refer to the ease with which innovations can be protected from imitation (Malerba and Orsenigo, 1993). If the level of appropriability within a sectoral system, is high, non-innovative firms will find difficulties in imitating innovations, however innovative firms will also find difficulties in learning by imitating activities. At the same time, if levels are low, the market may get saturated very fast, since innovations are rapidly imitated and diffused throughout the market.

In sectors with higher levels of appropriability conditions, it is expected to observe greater incentives in investing on innovative activities: an incentive effect on firm behavior. On the other hand, when the level of appropriability is low, it is expected to observe a higher level of imitation and intra-sector knowledge diffusion: an efficiency effect (Castellacci, 2007).

However, appropriability is difficult to measure directly, and what has been done through traditional methods has been to investigate it indirectly and qualitatively by examining the effectiveness of various means of appropriability, such traditional means include patents, licenses, secrecy, process lead time and related advantages (Harabi, 1995). On the other hand, appropriability is also highly related with technological opportunities, since higher opportunities and higher demand lead to stronger appropriability increasing private incentives to engage in R&D, but weaker appropriability reduces the cost of research and therefore increases opportunity for others (Klevorick et al., 1995), producing a trade-off between both conditions.

Cumulativeness Conditions

Finally, cumulativeness conditions are related with the extent to which current innovative activity builds upon previous knowledge (Malerba and Orsenigo, 1993; Castellacci, 2007). It has been suggested that cumulativeness variations have a direct effect on searching activities (Dosi and Nelson, 2010) and therefore on the capacity to increase innovative capability. The property of cumulativeness helps to gain insights on why new firms may or may not enter new markets, on why innovative capability in specific sectors grows faster than in others, and on how knowledge cumulativeness may dictate the dynamics of the overall sectoral system.

2.5 Complex Systems, Path-Dependence and Innovation Systems

The use of the Innovation Systems framework has brought undoubtedly several achievements, especially related with the understanding of the innovative process as a system, however, some shortcomings have been identified in the past few years. These shortcomings can be characterized as twofold: shortcomings related to the innovation systems framework per se and shortcomings related to the modeling of innovation systems.

First, economics, and neoclassical economics, has driven the study of innovation for the last sixty years. Thus, scholars have had difficulties in explaining what is in nature an interdisciplinary phenomenon, which not only accounts for economic variables but for evolutionary and co-evolutionary variables (Niosi, 2004; Godin, 2009).

Second, although the innovation systems approach emphasizes that the relationships among the actors are the drivers that cause changes in the behavior of the Innovation System (Godin, 2009), it does not explain how the components of the system compete for resources, in other words, how the relationships between the components are coordinated (Lee and Yoo, 2007). In this sense, due to the endogenous dynamics of sectors, changes in the boundaries, components, linkages and knowledge may occur as well (Malerba and Nelson, 2011).

Third, due to its static nature, the innovation systems framework lacks in representing the behavior changes on the system over time (Lee and Yoo, 2007). As Lee sustains, the systemic and dynamic patterns of interactions among the actors of an Innovation System are neglected topics of study in the NIS literature (Lee, 2002). During the evolution of a sector, changes may happen in the patterns of learning, in the knowledge base and in the market concentration due to dominant designs or new competencies (Malerba and Nelson, 2011).

And fourth, because of the complexity of the system (large number of actors and relationships) the main emphasis of empirical studies carried out has been on the system's statistics or comparative statistics, and none going onward more dynamic analysis (Carlsson et al., 2002; Niosi, 2004).

Furthermore, the study of innovation systems does not give any attention to "delay effects" or "time lags", i.e. there are long time delays between the moment a policy is launched and the moment the actual results of that policy are seen. In most cases it would take decades to see the effects of a policy or decision taken by one the innovation actors. Although the time lags have been studied in themselves, they have not been fully discussed in the context of an innovation systems (Lee, 2002).

The second type of shortcomings arises from the latter statement. So far, the current modeling of innovation systems has been based on mainly quantitative (statistical, econometric) and discursive approaches, such as expert-based judgments (Melo, 2001; van Raan, 2003). The OECD for example, has focused mainly on applying large scale surveys among their member countries in order to obtain data and measure input and output indicators, however, those static measures have fail in fully representing some of the behavior changes seen on Innovation Systems, especially those that depend on time. This dissertation does not imply that one approach may be better than another, certainly, statistical analysis may help in having a scientific way to cluster data, so it can be analyzed by several alternative methods; on the other hand, the advantage of opinion surveys is that they can estimate factors where hard data is not available by using the intuitive insights of experts on subjective aspects, improving the qualitative analysis. It simply claims that joint approaches - when used in parallel - can substantially improve innovation policy design.

Therefore, traditional approaches, such as those cited above, have many times failed in representing the complexity of Innovation Systems due to their inability to deal with the non-linearity and dynamicity found on IS structure and relationships. As Lundvall emphasized "a system of innovations...is also a dynamic system, characterized both by positive feedback and by reproduction...cumulative causation, and virtuous and vicious circles, are characteristics of systems and sub-systems of innovation" (Lundvall, 1992).

Statistical models are based on past conditions and depend on time-series analysis and regression forecasts; econometric models on the other hand are built upon changes in socio-economic conditions (GDP growth, demographics, etc.) (Lyneis, 2000), often including "judgmental" adjustments to their models in order to account for some non-linear behaviors. As Lyneis points out, these statistical approaches have not done a good job in explaining the complexity of non-linear, dynamic systems because they dont account for capturing the structure of the system which creates behavior over time (Lyneis, 2000).

On the other hand, the risks of using discursive approaches, such as expert-based judgments, is that they are influenced by subjective elements, limited knowledge and narrowness in mental models combined with respondent biases, resulting likely in a reflection of a nation's reputation rather than its actual state and since it lacks of a hard quantitative basis for sustaining their proposal, they may also fail in explaining the behavior changes over time (van Raan, 2003; Atkinson and Andes, 2009).

Structural modeling, through the use of System Dynamics helps in understanding patterns of behavior on complex systems in a more rigorous, scientific and consistent fashion by identifying the key-elements of dynamic complexity: time lags/delays, feedback loops and stocks and flows (Forrester, 1989a; Lyneis, 2000; Sterman, 2000).

System Dynamics help to understand how complex nonlinear systems behave, by describing the causal explanations that produce their performance and behavior through causal maps (qualitative approach) and by proposing alternate strategies through rigorous modeling and simulation methods for improving their performance by constructing scenarios and by designing more effective policies (Forrester, 1994; Sterman, 2000).

The proper use of System Dynamics for structural modeling provides certain advantages over other measuring and modeling approaches (Lyneis, 2000; Forrester, 1971a):

- More reliable forecasts of short to mid-term trends than statistical models, since in may complex systems, "structural momentum" dominates over "noise" in the short term (Lyneis, 2000).

- Means of understanding the causes of complex non–linear social systems behavior – as seen on Innovation Systems – and thereby changes on its structure as part of trend forecasting.

- Models that allow the determination of reasonable scenarios as inputs to decisions, strategies and policies.

- Takes account of a system's dynamic complexity – the counterintuitive behavior of complex systems that arises from the interactions of the agents over time the unanticipated events or side effects that policy makers face when the system behaves in a hardly predictable way.

Moreover, System Dynamics has been used in a variety of applications since its beginnings in the 1960's, taken special attention for this research, on macro-models, among them the modeling of the first world model that had as main aim to explain the complex dynamics of natural resource use on the planet (Forrester, 1971b), the following "Limits to Growth", an improved version of the world model (Meadows et al., 1971) and more recently on innovation studies (Janszen and Degenaars, 1998; Lee, 2002; Garcia et al., 2003; Lee and von Tunzelmann, 2005; Lee, 2006; Lin et al., 2006; Dangelico et al., 2010; Niosi, 2011; Tayaran, 2011)

2.6 Concluding Remarks

This Chapter has described the main theoretical base of the innovation systems approach. First, it has shown that knowledge is the main resource for innovation, as firms engage in different learning processes, ranging from R&D to acquisition of new equipment and training activities, in order to increase their knowledge base.

Second, it has described the nature of innovation, as being systemic, nonlinear and path-dependent process, through which different representations (or approaches) have been proposed, one of them being the innovation systems approach.

Third, innovation systems are composed by components, relationships and attributes, which define its state over time but also, the changes that occur through it.

Fourth, some important shortcomings of the innovation systems approach were described, which can be synthesized in the lack of studies exploring the dynamics of such systems, hindering policy design and implementation.

Fifth, it has suggested that methodologies such as system dynamics a modeling method for complex systems may help in understanding the dynamic nature of innovation systems.

3

System Dynamics

> The trend in science...has been toward reductionism, a constant breaking things down into little bitty pieces...What people are finally realizing is that that process has a dead end to it. Scientists are much more interested in the idea that the whole can be greater than the sum of the parts. Doyne Farmer apud Radzicki (1990).

This chapter discusses the theory behind system dynamics as well as its applicability in Innovation Systems. Therefore, the chapter begins with a description of its theoretical and methodological base and concludes with the discussion of dynamic patterns and interaction structures interaction of complex systems, visible by the use of System Dynamics.

3.1 Theoretical and methodological base of system dynamics

In the 1950's, Professor Jay W. Forrester at the Massachusetts Institute of Technology (MIT) began to study the phenomena of non-linearity and dynamics in social systems. Forrester had worked for a long time in industrial applications and servo control systems and automation and based on previous experience, intended to adapt them to the problems of management. Thus, Industrial Dynamics was proposed, which later came to be known as System Dynamics (SD) ((Forrester, 1958, 1989b; Sterman, 2000).

Forrester's interest in social systems and management problems was related to the difficulties faced by the tools - many with extensive mathematical basis used to solve such problems at the time. Thus, Forrester noted that just as in control systems, feedback loops existed in social systems as well, which responded - often negatively to manager or decision makers' interventions, thus complicating the management of these systems. Forrester developed a technique for modeling and simulation SD whose strongest ability is the identification of feedback loops within the system's structure, which cause the complex behavior observed in such systems.

System dynamics is based on the use of systems of differential equations which are solved behind the graphical user interface of specialized software such as Isee Systems iThink and Vensim from Ventana Systems. The systems of equations solved through numerical methods are composed of state variables (stocks), rates (flows) and time variables and their relationships, generating through the solution of the equations the dynamic and nonlinear behavior of the system.

Thus, this section describes the concepts, elements and relationships that build the theoretical and methodological base of SD.

3.1.1 Concepts and definitions

The wide range of problems of management and policy formulation requires from managers quick and effective decisions. However, the system in which these problems are located, often responds in an unpredictable way, creating unanticipated side effects (Forrester, 1971a; Sterman, 2000).

Jay W. Forrester was the first scholar to show interest in the structures of feedback in social systems, by arguing that the methods used to control and manage physical systems could be adapted to the problems of management (Forrester, 1971a). Thus, in 1958 Forrester published an article in Harvard Business Review introducing a technique he called Industrial Dynamics, designed to estimate the behavior patterns of complex, nonlinear and dynamic systems, by making feedback structures explicit and by taking into account the inherent phenomena of accumulation in social systems, by the use of computer modelling (Forrester, 1958).

Years later, Industrial Dynamics would become System Dynamics, since its applications go beyond industrial systems and even reach global scale applications, such as the "world model"[1]. In this sense, SD can be defined as the set of tools and techniques that allow modeling the structure and dynamics of complex systems, based on the use of computer simulations in order to formulate more effective policies (Sterman, 2000).

[1] The World Model was the first application of global scale, using System Dynamics. For details, see Forrester (1971b). World Dynamics. Tokyo, Nippon Keiei Shuppankei

SD simulations are the result of the numerical solution of the systems of differential equations. Equation 3.1 represents a generic integral equation used to represent the relationships in a SD model.

$$s(t) = \int_{t_0}^{t} [\sum_{i=1}^{i} F_i(s) - \sum_{j=1}^{j} F_j(s)] \cdot ds + s(t_0) \tag{3.1}$$

Where:

$s(t)$ = Stock at time t
$\sum_{i=1}^{i} F_i(s)$ = Sum of i inflows
$\sum_{j=1}^{j} F_j(s)$ = Sum of j outflows

Equation 3.2 presents and alternative representation to Equation 3.1, in this case, using difference equations.

$$\frac{d(s)}{dt} = Net\ change\ in\ stock = \sum_{i=1}^{i} F_i(t) - \sum_{j=1}^{j} F_j(t) \tag{3.2}$$

Where:

$\frac{d(s)}{dt}$ = Difference of stock as a function of time t
$\sum_{i=1}^{i} F_i(s)$ = Sum of i inflows
$\sum_{j=1}^{j} F_j(s)$ = Sum of j outflows

In Equations 3.3, 3.4 and 3.5, the nonlinear functions g, f and h are arbitrary and denote temporal changes necessary for the numerical resolution. Nowadays, the numerical solution of the systems of ordinary differential equations is done behind the interface of commercial software, specialized for SD, such as the Isee Systems iThink and Vensim from Ventana Systems.

$$rates_t = g(levels_t, aux_t, data_t, const) \tag{3.3}$$

$$aux_t = f(levels_t, aux_t, data_t, const) \tag{3.4}$$

$$levels_0 = h(levels_0, aux_0, data_0, const) \tag{3.5}$$

On the other hand, complex dynamic systems are governed by nonlinearity (types of relationships between variables that do not follow linear patterns) which produces internal forces that react to external stimuli, often in an unpredictable way.

Sterman (2000) sustains that these internal forces called feedback structures produce so-called side effects and unintended consequences when external interventions are made (new policies or new decisions) because feedbacks were not taken into account when the interventions were proposed. The author offers a real-case public policy example where a policy aimed at obtaining a particular result ended up producing another, unanticipated and undesired.

The example goes back to Romania in the 1960's, where the then President of that country had formulated a policy aimed at banning contraception, with the aim of increasing birth rate, the result was immediate and effective. However, in the long term, the system population of the country responded in an opposite way to the intervention and twenty years after, the birth rate had descended to the same level it was before the policy had been formulated. The non-predicted behavior was due to the economic problems the country was facing. The system could not sustain a higher birth rate and maintain it, because of the poor public services, lack of labor and other social problems, which forced the people to seek for alternative means of contraception, such as smuggling contraceptives, which eventually caused other new problems that affected the country for decades, such as the rise of infant mortality rates due to lack of care and abortions.

This tragic example portrays the complex structure of systems where the relationship and interaction among its elements produces feedback loops that force the system to regain balance, i.e. the state in which the forces of the system and their internal feedback structures are balanced.

From a more theoretical perspective, feedback structures are produced when two or more variables are linked, forming a closed loop, such as the third case in Figure 3.1. The loop produces a feedback structure which modifies the behavior of the entire system and at the same time is modified by the rest of the system.

According to (Sterman, 2006), a feature of social systems is that they possess such as biological systems feedback loops that self-regulate the behavior of the system based on the responses to reinforcement (positive) and balancing mechanisms (negative). The lack of knowledge of the most important reinforcing and balancing mechanisms of a particular social system produces interventions that do not generate the expected responses from the system (Sterman, 2000). Complex dynamic systems are also governed by delays, which occur when a "bottleneck" prevents time continuity

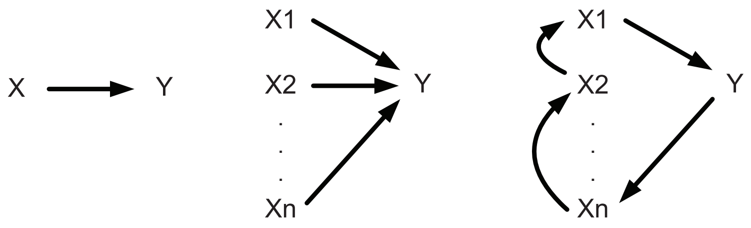

Figure 3.1: **Linear, Multilinear and feedback cause-effect structures.** - Source: Author

in the system. In terms of policy making, time delays are present between the formulation of a policy and its effects on the state of the system, resulting many times, in continuing corrective interventions to correct apparent gaps between desired and actual state even after enough corrective actions have been made, causing instability and fluctuations on the system (Sterman, 2006).

3.1.2 Causal Loop Model

The Causal Loop Model or Causal Loop Diagram (CLD) is a map representation showing the nonlinear links among variables in any domain (Sterman, 2000). An example of the use of CLD is shown in Figure 3.2.

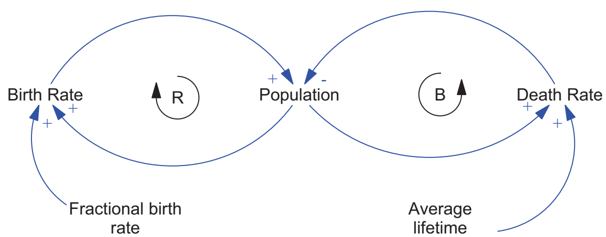

Figure 3.2: **Example of a causal loop diagram (CLD).** - Source: Sterman(2000)

Figure 3.2 denotes an example of the use of CLD. In the example, population is dependent upon a birth rate and a death rate, by links, represented by arrows. Each causal link is assigned a polarity, either positive (+) or negative (-) to indicate changes in the dependent variable when the independent variable changes.

A positive link means that if the independent variable (cause) increases, the dependent variable (effect) increases as well, and if the cause decreases, the effect will decrease as well. For example, if the fractional birth rate increases, the birth rate will increase as well.

A negative link means that if the independent variable (cause) increases, the dependent variable (effect) decreases, and if the cause decreases, the effect will increase. In the example of Figure 3.2, an increase in the average lifetime means that the death rate will decrease.

Based on the polarity of links, CLDs also represent the polarity of feedback loops. Thus, a feedback loop is a reinforcing one if the links' polarity is predominantly positive (represented by the letter R) and a loop is a balancing one if the polarity of their links is predominantly negative (represented by the letter B).

CLDs however, do not distinguish between stocks and flows the accumulation of resources and the rates of change that alter those resources (Sterman, 2000). In the example of Figure 3.2, both loops might alter the state of the variable "population", the CLD does not provide enough information to determine whether the population will grow or fall, since the rate of change (births less deaths) is not known. In this sense, System Dynamics uses a second approach to represent accumulation, the so-called stock and flow diagrams.

3.1.3 Stocks and Flows Model

Stocks and flows serve as indicators of the state of the system in a specific time as well as the speed of change in that state. Specifically, stocks represent state variables, which accumulate something of interest to the system, in physical and biological complex systems, examples of stocks are: the stock of glucose in the blood; the number of active smokers in a population (Sterman, 2000). Flows on the other hand, represent the rates of change in stocks, by increasing or decreasing their level, examples of flows are: birth rate, metabolic rate, etc.

The stock level is adjusted by the interactions within the system, through feedback loops and through the speed of input and output flows. The number of stocks in a complex system is related with the nth-order of the system of differential equations, i.e. a system which contains four stocks, produces a fourth order system of differential equations.

The diagramming conventions (originated by J.W. Forrester) are based on a hydraulic metaphor (Sterman, 2000). Thus, stocks are represented by rectangles, inflows are represented by a pipe (arrow) pointing into the stock; outflows are represented by pipes pointing out of the stock. Valves represent the control of flows and clouds represent the sources and sinks for the flows, normally outside the boundary of the model. Figure 3.3 shows the elements of the stock and flow diagrams.

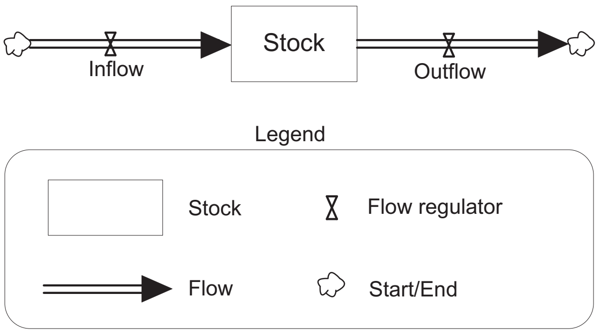

Figure 3.3: **Notation used to represent stocks and flows** - Source: Sterman(2000)

Another example, containing four stocks and several links between them, is shown in Figure 3.4.

The derivatives of the stocks in dynamic systems are nonlinear functions. In Figure 3.4, for example, the equation for the rate of change of $S4$ is:

$$\frac{dS_4}{dt} = f_4 \cdot (S_4, U_3, C_3) \tag{3.6}$$

where
S represents stocks
U represents exogenous variables
C represents constants

Stock and flow diagrams allow quantifiable results through simulation, often represented in the form of graphs, which intend to mimic the system's actual behavior. Scholars such as (Forrester, 1971a) and (Sterman, 2000) sustain that the result from the simulation (numerical integration of the system of differential equations) represents the behavior of the system. In the next section, some basic patterns of behavior will be introduced.

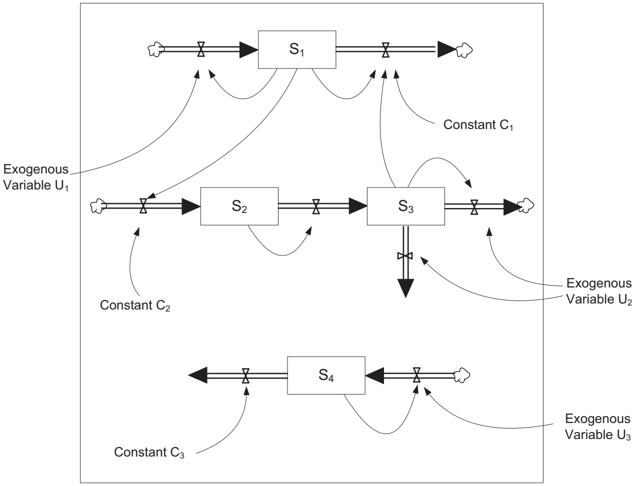

Figure 3.4: **Example of a dynamic system represented by stock and flows** - Source: Sterman (2000)

3.1.4 Model validation in system dynamics

As other quantitative approaches, system dynamics models need to be tested out in order to verify their consistency. Model validation in system dynamics however, takes a different path than traditional statistical validation because system dynamic models are not based on the system's past behavior, rather, on the internal structure that creates its own behavior (Senge, 1978).

From a more formal perspective, no model can be ever be validated per se, because, validation refers to a process in which the model is tested as truthful (Sterman, 2000; Grosser and Schwaninger, 2012). In this sense, all models are not validated but tested against devices so the modeler (and the users) can gain more confidence about the model.

Therefore, in system dynamics, validation refers to testing the model against several specific tests, in order to check the consistency of the model. Forrester and Senge (1980) describe validation as the "process of establishing confidence in the soundness and usefulness of the model".

Thus, system dynamics models are tested in two separate yet complementary ways: by testing its structure and by testing is behavior. According to specialized literature in the field, structural tests in system dynamics are those that aim to confirm if the adequate structure has been identified

identified (Forrester and Senge, 1980; Barlas, 1996; Sterman, 2000):

- Boundary Adequacy, considers the structural relationships needed to satisfy the purpose of the model, verifying is the chosen endogenous, exogenous variables are adequate.
- Structure verification, this test compares the structure of the model with the structure of the real system. In this sense, the structure of the model must not contradict the knowledge about the real system.
- Parameter verification, this test aims at verifying the validity of parameters or constants used in the model and to compare them with actual knowledge about them, in order to determine if they correspond conceptually and numerically to reality.
- Dimensional consistency, the test verifies if the units used in the variables, parameters and constants of the model are sound and coherent.
- Extreme conditions, the test verifies if the model behaves in an irascible way when extreme values are defined for the parameters or variables.

Behavioral validity tests on the other hand, are concerned with comparing the model generated behavior with the real system behavior (expected or actual). The following tests are part of it:

- Integration error, it tests if there is any change in the behavior of the system when the integration step is altered, or when the integration method is altered.
- Behavioral reproduction, the aim of this test is to verify if the behavior of the model is similar to the behavior observed in the real system.
- Behavior anomaly, this test is used implicitly during the model design and aims at identifying anomalies in the model behavior.
- Family member, this test verifies the capacity of scalability of the model to other realities or similar real systems.
- Surprise behavior, this test verifies if unexpected behavior is product of failures in model design or if they are actual behavior in the real system. This test also verifies the practical utility of system dynamics models when the second option is correct.

In addition, two tests are used to test the overall system structure and behavior: sensitivity analysis and system improvement (Sterman, 2000):

- Sensitivity analysis, this test aims at unveiling unexpected, irrational or erratic behavior when the variables and parameters of the model are altered within the range of analysis.
- System improvement, this test aims at verifying the use of the model in the sense that if is use has improve effectively the performance of the real system. This aim will only be reached when the new policies or actions are applied in the real system.

As (Qudrat-Ullah, 2005) suggests, the use of the tests is subject to the purpose of the model and of the nature of the system in study. In this sense, it is not necessary to run all tests on all system dynamics models but to choose the most appropriate ones to the needs of the model.

3.2 Behavior patterns of complex systems

System Dynamics postulate that the behavior of a complex system can be grasped through the identification of elements and feedback loops within the system, this postulate is usually stated as "structure drives behavior". Accordingly, (Wolstenholme, 2003) sustain that behavior patterns (known as system archetypes) can help in identifying key feedback structures within a system.

Sterman (2000) identified four basic system archetypes: exponential growth, goal seeking, oscillation, S-shaped growth, and overshoot and collapse.

The behavior of exponential growth occurs by the effect of reinforcing feedback loops, accelerating growth in the system (Sterman, 2000). In the exponential growth, as long as the state variable increases, the growing effect also increases. An example is shown in Figure 3.5.

The next behavior pattern, known as goal seeking is produced by the effects of negative (balancing) loops. In this type of structure, feedback loops produce a balancing effect in the system using a comparison mechanism between the desired and its current state Sterman (2000).

Insofar as there is a difference between the desired and current states, the corrective action of the negative feedback loops will continue. Thus, the greater this difference, greater the corrective action will be. An example is shown in Figure 3.6.

Similar to the goal seeking behavior pattern, in the oscillatory pattern behavior the state of the system is compared to its goal, and corrective

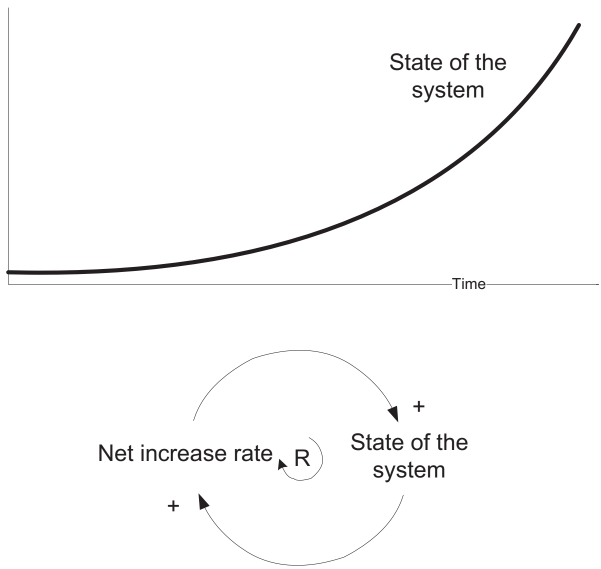

Figure 3.5: **Example of exponential growth behavior.** - Source: Sterman(2000)

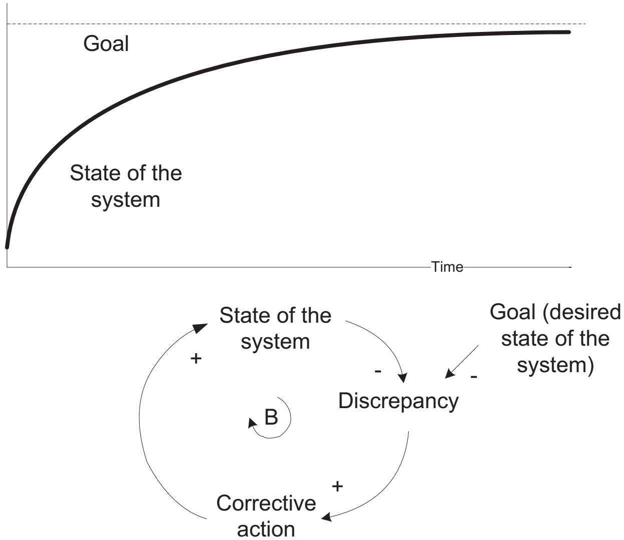

Figure 3.6: **Example of goal seeking behavior** - Source: Sterman(2000)

actions are taken to correct discrepancies. However, in this pattern of behavior there is constant overshoot, due to the presence of time delays which triggers a new correction in the opposite direction.

Many real systems present oscillatory behavioral patterns, such as the Kondratiev cycles, the so-called economic long waves with an average period of 60 years and which supposedly explain the rise and fall of economic activity through time (Forrester, 1981). Figure 3.7 shows a generic example of an oscillatory behavior.

The fourth basic behavior pattern is known as S-shaped growth. It is a special case of exponential growth in which a balancing feedback structure halts down growth (which was driven by a reinforcing feedback structure) forming a shape that resembles an "S". According to Sterman (2000) the nature of this pattern of behavior can be explained by looking at the "carrying capacity" of the system, which limits or constrains growth as the system approaches to it. Therefore, Forrester (1971b), Meadows et al. (1972) and others have called this pattern of behavior as the "limits to growth". An example is shown in Figure 3.8.

A classic example in SD literature is the book "World Dynamics" from Forrester, where he and a team of researchers at MIT develop a model to

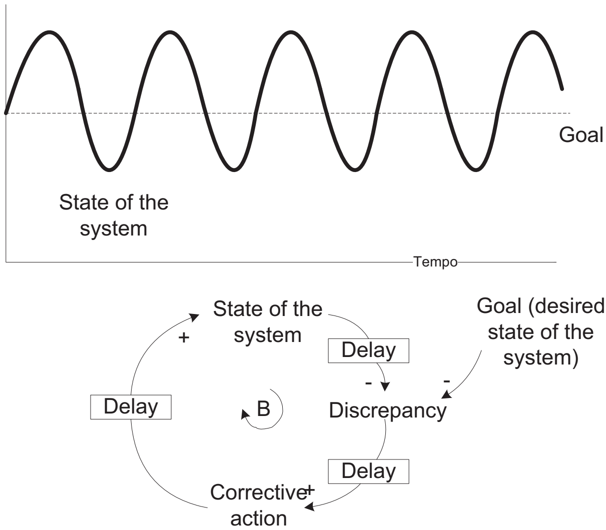

Figure 3.7: **Example of oscillatory behavior.** - Source: Sterman (2000)

explain the structure of interactions between the presence of human beings and the use of natural resources (Forrester, 1971b). In that model, it is natural resources that serve as the "carrying capacity" of Figure 3.8.

The last basic pattern of behavior is known as overshoot and collapse. It is derived from the S-shaped growth, but in this case, the " capacity" is not fixed, meaning it can be eroded or consumed through time, creating a second negative feedback limiting growth. As Sterman (2000) points out, as soon as the "carrying capacity" starts to decline, the state of the system follows, that is why, this pattern is also known as "boom and bust". Examples of overshoot and collapse in real life are the dotcom bubble of the 2000's and the real state bubble of 2008. Figure 3.9 shows a generic example of this pattern of behavior.

3.3 Previous system dynamics applications on the innovation domain

As previously mentioned in Section 2.5, in recent years some system dynamics applications have been found on the literature:(Janszen and Degenaars,

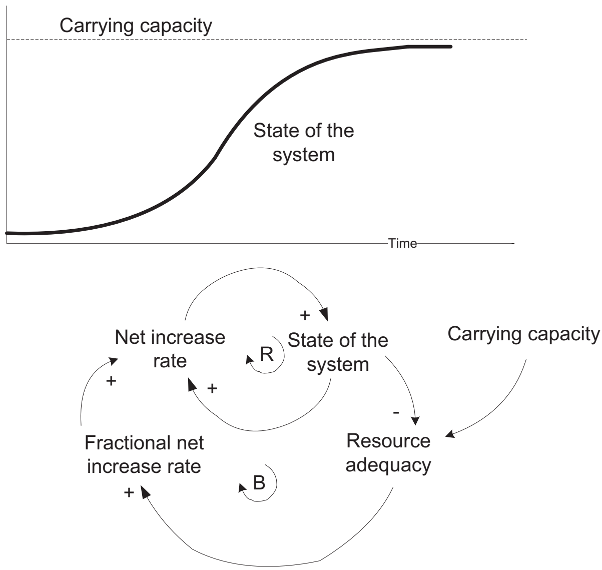

Figure 3.8: **Example of a S-shape growth behavior.** - Source: Sterman (2000)

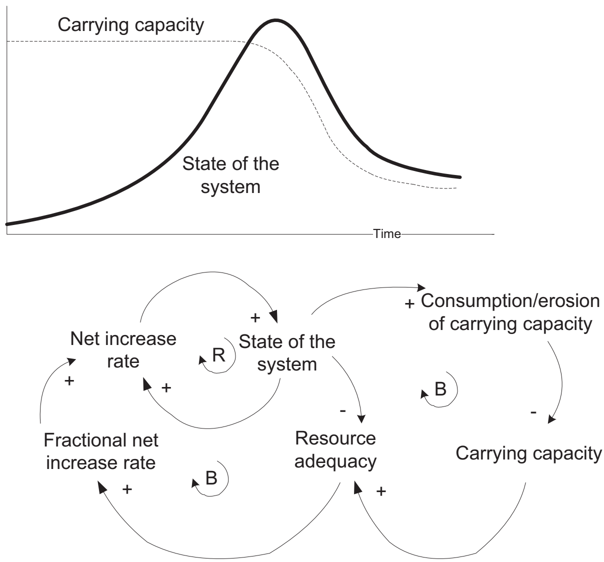

Figure 3.9: **Example of overshoot and collapse behavior.** - Source: Sterman (2000)

1998; Lee, 2002; Garcia et al., 2003; Lee and von Tunzelmann, 2005; Lee, 2006; Lin et al., 2006; Dangelico et al., 2010; Niosi, 2011; Tayaran, 2011).

Janszen and Degenaars (1998) investigated the relationship between regional attributes and the generation and exploitation in the Dutch Biotechnology Sector. The model is based on the analysis of two different national innovation systems, which compete on the same market. The shortcoming of this model is that it only accounts for two firms per each country, limiting in this sense, the interaction between a larger number of actors.

Linda (Tin-Lin) Lee also developed several studies using system dynamics to model the integrated circuit industry in Taiwan. In order to accomplish her objectives, Lee develops a modeling scheme in which it builds up different causal relationships and mathematical equations (Lee, 2002; Lee and von Tunzelmann, 2005; Lee, 2006). The shortcoming of this model is that it does not develop a fully enhanced causal structure for the knowledge and learning components, although it is the closest study to this Dissertation.

Garcia et al. (2003) uses system dynamics to test how firms decide on investing in R&D activities, depending on the balance between exploitation and exploration and assesses the performance outcomes for each decision. This model is more comprehensive on describing knowledge and learning related structures, and on proposing mathematical equations, though it only accounts for the behavior of individual firms.

Lin et al. (2006) uses system dynamics to explore the factors that affect the cluster effect. The authors identify money flows, technology flows, market flows and manpower flows. The major shortcoming of this work is that even though the causal structure is well explained and logic, it fails in representing a fairly simple stock and flow structure.

Dangelico et al. (2010) focused on the effects of knowledge, and thus they use system dynamics to model proximity dimensions (geographical, cognitive and organizational) in order to test the increase in knowledge creation and diffusion. The major shortcoming of this work is that the structure suggested by the authors was not based on sound and previous literature, thus the main variables and relationships can be questioned.

Finally, Tayaran (2011) has developed a complex model of the biotechnology sector in Canada, and used system dynamics to test several policies within the sector, related with exploitation and exploration activities. Although the model explores several causal and structural linkages it does not fully explain how learning processes occur within the system and how knowledge is created and acquired through those processes.

3.4 Concluding Remarks

This chapter has described the theoretical base behind system dynamics and shown its applicability for modeling complex systems.

First, the chapter has shown that system dynamics is a reliable simulation method to model systems with the characteristics of innovation systems: complex, nonlinear, path-dependent and ruled by feedback mechanisms.

Second, the chapter has suggested that there are different patterns of behavior that explain different circumstances in complex systems, whether there are growing or balancing or even logistic behaviors.

Third, some previous system dynamics applications have been briefly described, in which specific characteristics have been highlighted. Throughout that review, it has been shown that specific knowledge and learning processes have not yet been fully explored by previous applications.

Fourth, even though some previous system dynamics models were found and described, the vast literature on innovation systems would suggest a larger review of models, containing other modeling approaches as well. In this sense, a systematic review of the literature may be of use.

4

Research Method

This Chapter introduces the research method and procedures that were used to fulfill the objectives of this dissertation.

In order to accomplish the objectives, I reviewed the literature using a systematic procedure, aiming at collecting the key elements and relationships of an innovation system, then I summarized them into a modeling framework, which later was instantiated into a specific case study: the sectoral innovation system of the software sector in Brazil, using a system dynamics approach and data from a review of the published literature on the software sector in Brazil and from the PINTEC Database.

4.1 Modeling Framework Design

Since current literature on innovation systems offers a wide variety of models, components and linkages as part of these systems, the first step of this dissertation is to develop a modeling framework a framework synthesizing the various research perspectives into a comprehensive meta-model which brings up the key components and linkages needed for an innovation system to operate.

The modeling framework was based on an extensive review of the literature, based on the systematic review (SR) method, which offers a reproducible procedure that provides transparency to the critical appraisal of the literature in study and strengthens the capacity to make informed decisions by providing rigorous assessments of what has previously published on the subject (Khan et al., 2001; Petticrew and Roberts, 2006; Crossan and Apaydin, 2010).

There are several authors that describe the steps Systematic Reviews must comprise. We used the following procedure: research question formulation, data search and retrieval, quality assessment, data abstraction and analysis.

The objective of the review was to conduct a census of all published research on modeling innovation systems written in English between 1990 and 2009.

Three different electronic databases were used to retrieve bibliographic literature metadata that showed evidence on proposing models or representations of Innovation Systems. The meta-data was imported to Endnote X4 to facilitate the reading procedure. Other data procedures were used additionally (manual search on specific journals and communication with authors) to expand the scope of the review. The search procedure started out by reading each and every paper title (more than 2000 titles were), if a title seemed relevant to the previously defined selection criteria, it was selected for second phase, if not, it was excluded. The second phase consisted in reading out each and every abstract of the previously selected studies (1715 studies‘ abstracts were read), again, if the paper seemed relevant to the research it would go through phase 3. In phase 3, all studies were read thoroughly (72 studies were fully read), all studies that matched the selection criteria went through Quality Assessment and finally the ones that passed the quality assessment went to Data Abstraction and Analysis, a total number of 34 studies went through these final phase. In the following Sub-Sections each phase will be described in detail.

4.1.1 Systematic review of previous models

Research question formulation

Every systematic review begins with the formulation of a specific question. In this case, the question was: what are the components and linkages that have been defined as part of models used to represent, analyze or study innovation systems?

Data Search and Retrieval

First, the coverage of the literature was confined to studies devoted explicitly to propose new models or discuss previous ones within the IS domain. Therefore the following keywords were selected: “innovation system”, “innovation systems”, “system of innovation” and “systems of innovation”.

Second, the following online databases: Web of Science (Thomson Reuters), SCOPUS (Elsevier) and the System Dynamics Society Database were selected to conduct the search. The ISI Web of Science, owned by

Thomson Reuters, is considered to be the most important source of data for literature analysis in sciences (van Leeuwen, 2006; Uriona Maldonado et al., 2012). Elsevier's SCOPUS on the other hand, is the largest citation database of peer-reviewed literature in sciences . Finally, the System Dynamics Society Database is an updated and specialized source within the systems modeling domain, including peer-reviewed journal articles, conference proceedings, books and other bibliographical material.

Third, the search was limited to the period 1990 to 2009, before 1990 the literature offered little to no data. Then, the search strategy was designed by using the previously chosen keywords individually and in combination, using the following formulae:

For Web of Science:

TS=(innovation system) OR TS=(innovation systems) OR TS=(systems of innovation) OR TS=(system of innovation)
Timespan: 1990-2009
Databases = SSCI

For Scopus:

"innovation system" OR "innovation systems" OR "system of innovation" OR "systems of innovation"
In: Article Title, Abstract, Keywords
Document Type: Article
Published: 1990 to 2009
Subject Areas: Social Sciences

For the System Dynamics Society Database

This Database updates periodically a file with extension .enl (Endnote Format). This file was then imported to the Endnote X4 software were the search was used using the keywords: "innovation system" OR "innovation systems" OR "system of innovation" OR "systems of innovation".

Fourth, the keywords were broad and they did not take into account differences between Local Innovation Systems, Regional Innovation Systems, Sectoral or National Innovation Systems, because the purpose was to retrieve the total amount of articles that have dealt with the macro topic innovation systems in the Databases selected.

Electronic searches were performed by three researchers independently, Mauricio Uriona, Amruta Phadtare (AP) and Jatin Shah (JS)[1]. After iden-

[1] AB and JS are researchers of Research on Research Group Duke University, United

tifying and retrieving all articles archived electronically in the databases identified above, the metadata was imported from Web of Science, Scopus and the SDS Database to .enl format (Endnote format). Endnote X4 software was used then to ease the process of reading each one of the titles, abstracts and full-texts accordingly.

Selection Criteria

Based on the results of the initial search, the selection criteria was defined to filter and shortlist articles that would qualify for the systematic review and assist to answer the research question. Each reviewer independently evaluated each of the shortlisted articles based on the following criteria:

1. The article must use or propose a model (quantitative or qualitative) and that it must be applied to an Innovation System

2. Articles published in peer-reviewed indexed journals

3. Articles in English language

These criteria helped in filtering out a large number of articles dealing with "innovation systems" and not proposing models of it.

Hand search

Hand-search procedure helps in wiping out critical sources that might provide additional data to the review process (Petticrew and Roberts, 2006). In order to avoid missing any relevant articles, two of the authors carried out a hand search (manual search) in the following journals: Research Policy, Technovation and in the System Dynamics Society Database.

The journals Research Policy and Technovation were chosen because they were the two publications with most articles within our initial pool of articles. It is worth mentioning that Research Policy accounts for the largest quantity of articles and citations in the innovation systems domain, therefore becoming the most relevant journal in the field (Uriona Maldonado et al., 2012).

Communication with authors

Further, to confirm that all relevant study articles were identified and retrieved, authors of articles shortlisted during the review process were

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emailed, to determine the existence of any other relevant published article related to the research question.

Communication with authors was done in two times with an interval of 60 (sixty) days between them. The time interval was broad so it could give authors enough time to reply. In the first communication, all the authors with available electronic mail addresses were emailed. The second communication (60 days after) worked as a reminder to authors that had not yet replied to the first email. Both e-mail templates can be found in Appendix 1.

Validity assessment

One external reviewer repeated the literature search using our inclusion and exclusion criteria. The blinded researcher was not informed about the objective of the systematic review. The results obtained by the external reviewer were comparatively similar to the ones obtained in the first phase.

Quality assessment

As a next step, two of the reviewers (MU, AP) assessed the quality of articles retrieved during the literature review process. The assessment is qualitative in nature, therefore, it depends on the worldview of the reviewers. Each one performed a separate assessment and then the results were compared to see if there was convergence.

The assessment criteria included the following elements: theoretical robustness; practical implications; method, data and supporting arguments; generalizability and contribution.

- Theoretical robustness is related to the degree of theoretical quality of the study, measured by the quality of its bibliographical references and the arguments used by the authors to sustain their ideas.

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Practical implications is related to the degree of practicality of the study, i.e. how practical are the ideas exposed on the study.

Method, data and supporting arguments, related to quality of the methodological issues of the study.

Generalizability, the degree to which results from the study could be generalized to other contexts.

Contribution, related to the perceived degree of theoretical contribution for the subject of the study

Data abstraction and analysis

Finally, qualitative data from the final list of articles was extracted out into a spreadsheet. All extracted data was populated under specific headings that included : Author, Title, Year, Aim/Objective, Hypothesis/Assumptions, Research Methodology, Modeling Approach, Structure (Relationships and interaction among the elements/variables of the model), Time Boundary, Data Input (Qualitative/Quantitative), Target groups, Elements of the model, Variables, Implications, Summary, Limitations and Conclusions. Afterwards, data was cross-examined in order to classify the models into similar categories, looking for common elements and characteristics, contemplating a classification of the models by the approach they used, describing the main characteristics of each approach.

It is also described the information flow from the search on the electronic databases to the selection of the final studies for the review process as well as other results such as the distribution of studies per year and the frequency of publications in every journal.

4.1.2 Modeling Framework Design

In this Section each component is described in detail, explaining the main flows and linkages and their theoretical base.

4.2 Causal Loop Model Design

After the previous models in the literature were analyzed through the systematic review, a System Dynamics model was built based on Sterman (2000) and Morecroft (2007) proposed procedures for system dynamics modeling. System Dynamics was explained in detail in Chapter 3.

The first step was to design the causal loop model or causal loop diagram (CLD) by using the notation of Section 3.1.2 Causal loop models help in representing feedback loops and their polarity, which produce the behavior observed in complex system. In this phase, the main feedback structures of the software sectoral innovation system in Brazil were identified.

As Sterman (2000) sustains, CLDs serve as "hypothesis" that offer explanations for the behavior observed in the real system by describing the polarity of their loops and the interactions among them. These hypothesis are the first step in the process of modeling complex systems and in order for them to be tested, they were formalized into computer simulation models.

4.3 Model Instantiation

This phase presents the data extracted from PINTEC - Industrial Research on Technological Innovation - editions 2005 and 2008 for the Software Sector in Brazil that will be used to design the stock and flow model. PINTEC was designed by the Brazilian Institute of Statistics and Geography (IBGE) and is considered to be the most comprehensive source on statistical data on firms product and process innovations (technological innovations) from an official entity in Brazil.

PINTEC includes questions about RD and non R&D innovative activities, information sources for innovation, cooperation between agents and other data related with innovation. Few datasets contain information on both innovation objectives and sources of knowledge for individual firms. The two latest datasets from PINTEC were used, PINTEC-2005 and PINTEC-2008. In all cases, PINTEC sampled firms with ten or more employees, used the sample design process proposed by the Oslo Manual and used in the Community Innovation Surveys (CIS) in Europe, which has given it broad credibility and confidence (Kannebley et al., 2005; IBGE, 2010).

PINTEC-2005 includes data from 95.301 firms from the extractive, manufacturing and service sectors (IBGE, 2007). Particularly, two sub-categories in PINTEC-2005 were used: "Software consulting" and "Other information technology and services related activities", with a total sample of 3811 firms. The purpose was to use both sub-categories as proxies for the Software Sector in Brazil for the period 2003-2005.

PINTEC-2008 is the newest one, including data from 106.822 firms from the extractive, manufacturing and service sectors (Kannebley et al., 2005; IBGE, 2010). Particularly, two sub-categories in PINTEC-2008 were used: "Development and licensing of computer programs" and "Other information technology services". The purpose was to use both sub-categories as proxies of the Software Sector in Brazil with a total sample of 2514 firms for the period 2006-2008.

Both data sources, PINTEC-2005 and PINTEC-2008 served to extract data about parameters, variables and constants needed to formulate de stock and flow model. In addition, a detailed analysis of the Software Sector in Brazil helped out in collecting additional data from scientific journals, books, reports, associations and official documents (See Appendix 2).

4.4 Stock and Flow Model Design

In this phase, a stock and flow model was designed. This model was based on the modeling framework of Section 4.1, on the CLD model from Section 5.3, on data from PINTEC survey from the Software Sector in Brazil (Section 6.1) and on data from other additional sources (Appendix 1) and, when data lacked, as Oliva (2003) suggest, of educated guesses. The stock and flow model translates previous sources of data, linkages and components into differential equations which are solved through numerical integration methods.

The stock and flow model is presented using the components proposed in the modeling framework: Financing and Funding, Science and Technology, Technological Production, Consumer Market and Human Capital, therefore each component is described in detail, at the equation level.

4.5 Model Validation in System Dynamics

The model was tested against structural and behavioral tests, which are explained in Section **??** First, structural validity tests were performed: boundary adequacy, structure verification, parameter verification, dimensional consistency, extreme conditions. Second, behavioral validity tests were performed: integration error, behavioral reproduction, behavior anomaly, family member, and surprise behavior (Forrester and Senge, 1980; Barlas, 1996; Sterman, 2000).

4.6 Simulation Experiments

Several simulation experiments were conducted, in order to observe changes in the dynamics of the sectoral software system in Brazil, by using the different conditions that shape its technological regime the conditions in which firms innovative activities takes place (Castellacci, 2007). Those conditions, as described in Section 2.4.2 Literature Review, are: technological opportunities, properties of the knowledge base, appropriability conditions, and cumulativeness conditions. First, I test how different rates of learning affect the dynamics of the software sectoral innovation system. Learning activities are modeled as flows that head on to STI knowledge base or to DUI knowledge base.

Second, I test how different levels of technological opportunities impact on the overall dynamics of the sectoral software system in Brazil. Technological opportunities are described by the ease with which new or improved solutions to problem solving activities are found (Castellacci, 2007).

Third, I test how different levels of appropriability conditions impact on the overall dynamics of the sectoral software system in Brazil. Appropriability conditions can be regarded as changes in the rates of learning by imitating one of the learning types used by firms to accumulate DUI knowledge. Fourth, I test how knowledge helps in building up new innovative capability through changes in the levels of cumulativeness conditions.

The previous experiments help in showing the relevance of the model, which could be used to perform infinite sets of alternative simulations by experimenting with different sets of changes and by observing their impact on the system. Moreover, they may help in shedding more light on how knowledge and learning processes affect the overall dynamics of the Software Sectoral Innovation System in Brazil.

5

Modeling Framework and Causal Loop Model Design

This chapter introduces the design of a new modeling framework that aims at describing the main components and linkages of an innovation system, that are related with knowledge and learning processes. In this sense the chapter is structured in the following way: the first Section describes in detail the results of the systematic review of the literature, which served to identify the components and linkages proposed in previous literature. The second Section aims at describing the framework design, by describing each component and their main linkages[1] . The third Section describes the feedback loops that are structured by means of the interaction of the previously described components, by using causal loop diagrams from system dynamics. The fourth and last Section delineates the main conclusions withdrawn from the previous findings.

In addition, each Section of the chapter ends up with a short synthesis describing its main findings and conclusions and highlighting their attendance to the research objectives of this dissertation.

[1]Portions of a previous version of these sections have been published in the 9th Globelics Conference (2011) and the current version has been accepted in the 10th Globelics Conference (2012)

5.1 Results of the review of previous models of innovation systems

This section presents the results from the systematic review on previous models of innovation systems.

5.1.1 General Results

Systematic literature search was carried out in the previously cited electronic databases in order to find all previous IS models by using the search phrases innovation system, innovation systems, system of innovation and systems of innovation for the period 1990-2009. Prior to 1990, the literature offered little to no data. The search was restricted to studies published in English-language journals. The contents of 2096 abstracts or full-text manuscripts identified during our literature search were reviewed to determine whether they met the criteria for inclusion (773 from Web of Science, 1149 from Scopus and 174 from the System Dynamics Society Database).

The Hand Search procedure initially yielded 33 (thirty three) articles from Research Policy and 9 (nine) articles from Technovation. After a joint analysis of the pool of 42, we came up with a final list of 19 papers which were read in full text and finally we selected 8 articles and added them to the previous 26. Communication with authors yielded on 11 (eleven) additional articles, however, after a joint analysis, we concluded that none of them was relevant to our study. The final number of studies to be included in the qualitative synthesis was 34, as shown on Figure 5.1.

5.1.2 Data Analysis

Original articles were retrieved for data abstraction. Two investigators independently collected data on author, title, year, aim/objective, hypotheses/assumptions, research methodology, modeling approach, structure, time boundary, data input, target groups, elements of the model, variables, implications, summary, limitations and conclusions for each article. The final list of 34 articles is shown in Figure 5.2.

Data analysis initially evidenced that there is an adequate representation for most years, in terms of number of articles, although it is also evidenced an increase in the last 5 years of the sample, as shown on Figure 5.3.

In terms of the publication sources, Figure 5.4 shows the list of publications used and their frequency.

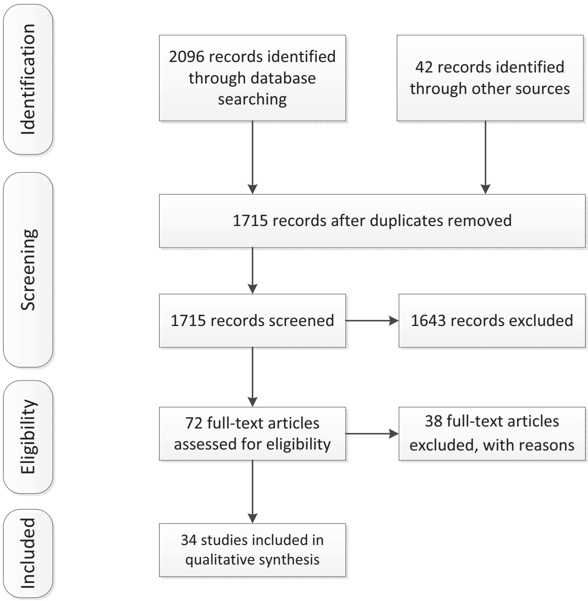

Figure 5.1: **Flowchart of the Systematic Review process** - Source: Author

#	Author	Title	Year
1	Autio, E. and A. P. Hameri	The structure and dynamics of technological systems: A conceptual model	1995
2	Hubner, H.	Decisions on innovation and diffusion and the limits of deregulation	1996
3	Johannessen, J.A., J.O. Dolva, and B. Olsen	Organizing innovation: Integrating knowledge systems	1997
4	Lopez-Ortega, E	A Dynamic Model for Regional Competitiveness Based on the Regional Innovation System	1997
5	Janszen, F. H. A. and G. H. Degenaars	A dynamic analysis of the relations between the structure and the process of National Systems of Innovation using computer simulation; the case of the Dutch biotechnological sector	1998
6	Kumaresan et al	An integrated network approach to systems of innovation—the case of robotics in Japan	1998
7	Padmore T. and Gibson H.	Modeling systems of innovation An enterprise centered view II: A framework for industrial cluster analysis in regions	1998
8	Nasierowski, W. and F. J. Arcelus	Interrelationships among the elements of national innovation systems: A statistical evaluation	1999
9	Mohannak, K	A national linkage program for technological innovation	1999
10	Etzkowitz, H. and L. Leydesdorff	The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations.	2000
11	Shyu, J. Z., Y. C. Chiu, et al.	A cross-national comparative analysis of innovation policy in the integrated circuit industry	2001
12	Liu, X. and White S.	Comparing innovation systems: a framework and application to China’s transitional context	2001
13	B. Carlsson et al.	Innovation systems: analytical and methodological issues	2002
14	Gür, U. and S. Güven	Assessment of Possible Effective Strategies in the Transition Process to a Knowledge-Based Economy : The Case of Turkey	2002
15	Intarakumnerd P et al.	National innovation system in less successful developing countries: the case of Thailand	2002
16	Loof, H. and A. Heshmati	The link between firm-level innovation and aggregate productivity growth: a cross-country examination	2003
17	Unger, B. and M. Zagler	Institutional and organizational determinants of product innovations	2003
18	Lee, T.L. and N. von Tunzelmann	A dynamic analytic approach to national innovation systems: The IC industry in Taiwan	2005
19	Devine, S.	The viable systems model applied to a national system of innovation to inform policy development	2005
20	Graversen, E.K., E.K. Schmidt, and K. Langberg	Dynamic research environments: a development model	2005
21	Hsu, C.W	Formation of industrial innovation mechanisms through the research institute	2005
22	Buesa M. et al.	Regional systems of innovation and the knowledge production function: the Spanish case	2006
23	Galanakis, K.	Innovation process. Make sense using systems thinking	2006
24	Katz, J.S.,	Indicators for complex innovation systems	2006
25	Lee, T. L	An alternative approach to technology policy assessment: Dynamic simulation analysis of Taiwan's IC industry	2006
26	Van Looy, B., et al.	Scientific capabilities and technological performance of national innovation systems: An exploration of emerging industrial relevant research domains	2006
27	Ahlqvist, T. and T. Inkinen	Technology foresight in scalar innovation systems: A spatiotemporal process perspective	2007
28	Chaves, C.V. and S. Moro,	Investigating the interaction and mutual dependence between science and technology	2007
29	Walwyn, D.	Finland and the mobile phone industry: A case study investment from government-funded research and of the return on development.	2007
30	Bergek A. et al.	Analyzing the functional dynamics of technological innovation systems: A scheme of analysis	2008
31	Chen, C.K.,	Causal modeling of knowledge-based economy	2008
32	Fagerberg J. and Srholec M.	National innovation systems, capabilities and economic development	2008
33	Stamboulis, Y	Exploring the System Dynamics of Innovation Systems	2008
34	Hung, S.W	Development and innovation in the IT industries of India and China	2009

Figure 5.2: **List of studies selected for the data abstraction step in the Systematic Review** - Source: Author

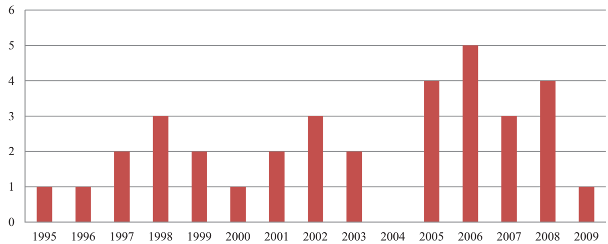

Figure 5.3: **Distribution of articles per publication year** - Source: Author

Publication Source	Frequency	%
Research Policy	11	32%
Technovation	5	15%
Technology in Society	3	9%
Prometheus	2	6%
Systemic Practice and Action Research	1	3%
Scientometrics	1	3%
Research Evaluation	1	3%
Management Decision	1	3%
Int. J. Technology, Policy and Management	1	3%
Int. J. of Human Resource Management	1	3%
Innovation	1	3%
Fennia	1	3%
European Planning Studies	1	3%
European Journal of Operational Research	1	3%
1997 SD Conference	1	3%
2002 SD Conference	1	3%
2008 SD Conference	1	3%
Total	**34**	**100%**

Figure 5.4: **Frequency of studies per publication title** - Source: Author

According to Figure 5.4, Research Policy was the most frequent publication source with a total of 32% of all studies selected, followed by Technovation with 15%, equaling a total of 47%.

5.1.3 Modeling approaches

There is a predominance of conceptual models (50%) as shown on Figure 5.5. The second modeling approach was the econometric one (23%) and third, System Dynamics with 18% and other modeling approaches adding up 9%.

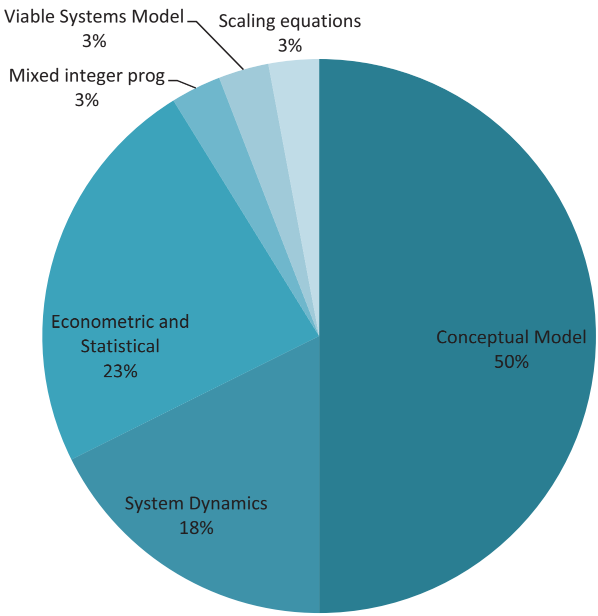

Figure 5.5: **Modeling approaches used in the studies** - Source: Author

Conceptual models are qualitative representations of Innovation Systems. A total of 17 papers (50% of the total) focused on this type. Todorov and Marinova (2011) point out that purely-theoretical models can be very robust as tools in search for a common or shared understanding. In this sense, all 17 papers work on setting comprehensive understandings of what constitutes an innovation system, mainly on showing up and proposing key components, such as financial, technological and human components. Since the relationships among the actors of an innovation system are the main drivers of its performance, conceptual models help in make those relationships explicit, at least at the conceptual level, so that scholars and policy makers can have a holistic view of the system (Godin, 2009).

However, as Todorov and Marinova (2011) suggest, qualitative models lack in testable and measurable procedures. Thus, the following types, which are quantitative-oriented models, focus on a more measurable base.

The second group comprehended econometric models, which are essentially statistical models applied to economics science and as any quantitative modeling approaches, they offer a very valuable role in representing reality with measurement and calculation-based indicators (Geweke et al., 2008; Todorov and Marinova, 2011), therefore, in this category we added both purely statistical as well as econometric models. A total of 8 articles (23%) corresponded to this category.

Specifically, the papers found dealt with the relationship between productivity growth and innovative performance (Loof and Heshmati, 2003); innovation determinants for several countries (Unger and Zagler, 2003); scientific capabilities and technological performance (Van Looy et al., 2006); establishing typologies of innovation systems based on empirical data (Buesa et al., 2006); two-way relationship between Science and Technology (Chaves and Moro, 2007); public expenditure on R&D and economic growth (Walwyn, 2007); the causal relationships within knowledge-based economies (Chen, 2008) and finally, with the role of capabilities in economic development (Fagerberg and Srholec, 2008).

The third most used modeling approach was System Dynamics with 6 papers. System Dynamics is a modeling approach that represents complex systems by identifying the key feedback loops that relate the elements of the system (See Chapter 3). Specifically, the SD-related studies focused their attention on the relationship and impact of Science and Technology Parks on Regional Innovation Systems (Lopez-Ortega, 1997); the relationship between regional attributes and the generation and exploitation of technology (Janszen and Degenaars, 1998); the modeling of Sectoral Innovation Systems and Technological Innovation Systems (Lee and von Tunzelmann, 2005; Lee, 2006); an improved and shared understanding of the innovation system among several stakeholders (Galanakis, 2006) and finally, the relationship between resource allocation and innovation (Stamboulis, 2008).

Among other modeling approaches, three papers were identified. Gur and Guven (2002) used Mixed Integer Programming to test possible strategies a country might use to move to a Knowledge-based Economy; Devine (2005) used Viable Systems Model (VSM) on Innovation systems by applying the concepts on a generic small economy; and Katz (2006) proposed a scale-independent measure to compare innovation systems, under the theory of complex systems.

5.1.4 Synthesis

In this Section, based on a systematic review of the literature, previous models of innovation systems were identified and classified into four groups: conceptual models, system dynamics models, econometrics models and others. It was shown that there is a predominance of conceptual models (50%), followed by econometric models (23%), in third place, system dynamics models with 18% and finally, other modeling approaches adding up to 9%.

The large amount of models and modeling approaches has evidenced that there is no consensus on a specific set of components and linkages composing an innovation system. Although it may be argued that the variety of models and modeling approaches are specific to each study and that in fact their diversity enriches the innovation systems literature, my argument is that since models are no more than abstract representations of a reality, they may be subject to bias, lack of knowledge, subjectivity, and so on, thus, by proposing a framework which would coherently and logically built based on a large synthesis of previous models there could be convergence of ideas or patterns in terms of what is actually contained by the model, the boundaries, the linkages and the components themselves - which actually may prove even more valuable than the current vast diversity of models out there.

5.2 Framework Design

Out of the 34 papers, 14 proposed models at a higher-level, meaning models with a perspective on the whole innovation system rather than on specific parts. Based on the analysis of the 14 studies, data related to the key components and linkages was extracted and synthesized on this Section, and presented in the form of a modeling framework for innovation systems a representation of the key components and linkages that are needed for innovation systems to operate.

The translation of this data into the modeling framework followed the guidelines of Bunge (2003), which characterize the types of factors that could be part of any model of complex systems. In this sense, the framework presented here includes economic and political factors. In addition, Bunge (2003) also suggests that models are composed by: components, environment, structure and mechanisms.

The components of the modeling framework are Financing and Funding component, a Science and Technology component, a Technological Production component, a Consumer Market component and a Human Capital component. In terms of environment, the modeling framework proposes to by endogenous in nature, which means that the environment shares space with the components. The structure as understood by (Bunge, 2003), is shown in the modeling framework as relationships and linkages between and within the components, basically flows of knowledge, information, people and money. Finally, the mechanism that is behind the modeling framework are the various types of learning used by firms, in order to acquire external or create internal knowledge. Figure **??** shows the five components mentioned above, illustrating the main linkages, flows and mechanisms.

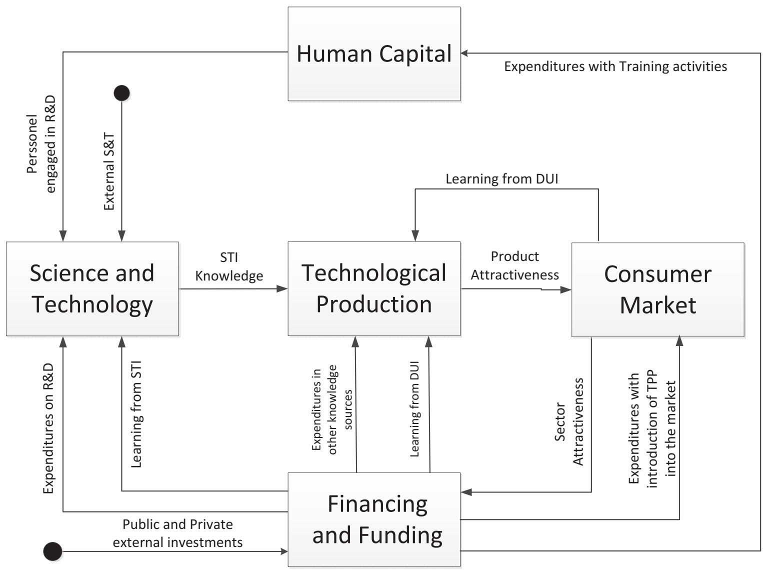

Figure 5.6: **Modeling framework for innovation systems** - Source: Author

The components described before do not group actors or institutions; its focus is on the specific functions or processes that are performed by them which can be grouped by using the main goal of their functions as grouping criteria. For example, different institutional actors within the innovation system are responsible for using and diffusing financial capital flows (be they banks, public funding agencies, firms, etc.) throughout the system; thus, financial capital flow can group functions such as Public R&D Expenditures, Private R&D Expenditures, Firm Expenditure on Machinery and Equipment, etc. as part of a Financing Component. Furthermore, institutional actors can be part of the remaining components if they perform functions related to their goals.

In the following Sections, each specific component will be describe, including the main inflows and outflows, key state variables and their conceptual basis.

5.2.1 Financing and Funding Component

Access to capital is vital to supporting innovation in firms. Transforming ideas into commercial products requires significant resources including, but not limited to R&D. In this sense, the agglomerate of functions in the innovation system dedicated to drive financial capital flows within the system are vital for its performance (Unger and Zagler, 2003).

R&D spending at universities creates opportunities for university-industry partnerships that can benefit retention of talented students. R&D investment by firms and government is also critical for developing new or improved products and processes that can drive wealth-creation and prosperity (COC, 2005).

Funding sources can be private, like venture capital, or public, like the case of publicly-funded R&D. Both examples resemble an external source of funding, but firms also invest part of their profits on future internal innovation activities, suggesting internal sources of funding as well (Walwyn, 2007; Bittencourt, 2012). All of these functions are grouped to form this component. Out of the pool of studies accounting for a financial component, the literature offered several denominations, which are shown in Figure 5.7.

Most of the studies proposed a financial component as part of the innovation system. Despite differences in how they have been named, there is a high consensus that financial and funding functions must be present on any innovation system.

In terms of financial inflows, the attractiveness of the sector determines a level of financial performance (as compared to other sectors) that serves as indicator for agents to decide on investing or not on the sector. Comparison between different innovation systems is a mechanism to learn from

Financing and Funding Component	
Denomination	Authors
National, regional and other financial systems and institutions	(Johannessen, Dolva, & Olsen, 1997; Mohannak, 1999)
Investment systems	(Lopez-Ortega, 1997)
Venture capital and government subsidies	(Janszen & Degenaars, 1998)
Financial Resources	(Hung, 2009; Shyu, Chiu, & Yuo, 2001; Stamboulis, 2008)
Capital Market (Financial Market)	(Lee, 2006; Lee & von Tunzelmann, 2005)
Public Finance and Private Finance	(Ahlqvist & Inkinen, 2007)

Figure 5.7: **Financing and Funding Component** - Source: Author

better practices (Niosi, 2002).

Financing and funding decisions are influenced by the overall performance of innovation system, as measured by the variable Sector Attractiveness (SAT). This variable defines the financial performance of the sector which helps firms and government in making their decisions on the investment size of innovative activities.

Specifically, three types of investments or expenditures are taken into account: 1) self-investments on innovative activities, made by the firm who introduced process and product innovations and made profits from them coming from the consumer market component modeled as the variable Privately-owned Funding (POF); 2) external private investments, made by the private sector (other firms) wishing to invest on innovative activities on the sector, represented by the variable named as Private-external Funding (IPR); and 3) government funding, which is made through funding programs from Federal, State and Local Agencies, which is represented by the variable named as Government Funding (IPU).

In terms of financial and funding out flows, this component includes In-House R&D Expenditures (IRD) and External R&D Expenditures (ERD) which determine specific expenditure (from private and public sources) on R&D by firms in the sector, performed in the Science and Technology component. It also includes financial outflows to the Human Capital component, modeled by the variable Expenditure with trainings (EWT). Several other expenditures outflow to the Technological Production component, modeled as Expenditures with External Knowledge (EEK), with

Software (ESO), with Machinery and Equipment (EME) and expenditures with other technical preparations and setup (EOP). In terms of outflows to the Consumer Market component it includes the variable named as expenditures with the introduction of technological innovations into the market (EWC). Figure 5.8 shows the previously described variables and flows in graphical format.

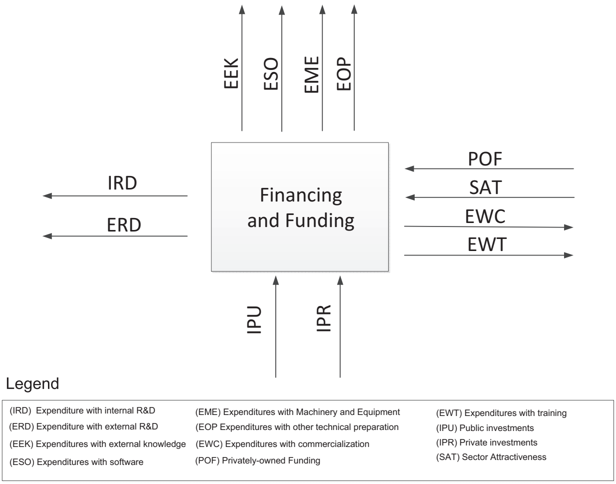

Figure 5.8: **Financing and Funding Component Main Structure** - Source: Author

5.2.2 Science and Technology Component

This component depicts the creation and acquisition of scientific and technological knowledge, creation, in terms of in-house R&D and acquisition through external R&D, described by Jensen et al. (2007) as proxies of the latent variable known as Science, Technology and Innovation Knowledge (STI).

STI Knowledge produces a mode of innovation coming from several S&T agents, like research institutes, universities, R&D departments in firms, R&D organizations and qualified human capital (Hubner, 1996), it is the traditional mode of innovation as discussed by specialized literature. See Jensen et al. (2007).

Figure 5.9 shows the different denominations found in the review of studies to name a scientific and/or technological component as part of the innovation system.

Science and Technology	
Denomination	**Authors**
Scientific and technological knowledge production system (research institutes and partly, firms)	(Galanakis, 2006; Hubner, 1996; Hung, 2009; Shyu et al., 2001)
Research and Development	(Hung, 2009)
R&D environments	(Johannessen et al., 1997)
Scientific subsystem	(Janszen & Degenaars, 1998)
Universities and higher degree institutions	(Ahlqvist & Inkinen, 2007; Etzkowitz & Leydesdorff, 2000; Hsu, 2005; Mohannak, 1999)
Science and Technology transfer	(T. L. Lee, 2006; T. L. Lee & von Tunzelmann, 2005)

Figure 5.9: **Science and Technology Component** - Source: Author

In addition, several previous models have taken into account the importance of R&D activities for technological innovation. In the Chain-linked model for instance, Kline and Rosenberg (1986) highlight the importance of the interactions between the central chain of innovation and the scientific and technological knowledge base. Lee (2002) and later Lee and von Tunzelmann (2005) describe the inter linkages between R&D and innovation systems by highlighting its importance for product and process innovations. And Tayaran (2011) also links R&D effort with the absorptive capacity of firms to acquire external knowledge and with internal knowledge creation.

From a conceptual perspective, this component focuses on the growth of STI knowledge, thus becoming the core variable of the component. Two learning types, learning by internal search variable and learning from external advanced S&T are taken out from Bittencourt (2012).

According to Bittencourt (2012), learning by internal search refers to the internal research processes of firms when searching for solutions to their problems. In this dissertation internal search is defined as in-house R&D activities. On the other hand, for the author, learning from external advanced S&T refers to the acquisition of external R&D and other advanced S&T agents which can be applied to the problems firms face when developing technological innovation.

In addition, the levels of employment of personnel with advanced degrees and occupied in S&T activities is also a traditional indicator of STI knowledge (Jensen et al., 2007).

From a modeling perspective, this component interacts with three basic types of flows, knowledge flows, information flows and financial flows (Niosi, 2002). Knowledge flows, embedded in the qualified Human Capital that is engaged in STI activities (PhDs, Masters and Graduates); information flows from in-House R&D, Testing Centers, Universities and Research Institutes; and financial flows, from Firms reinvesting on STI activities, Private Sector investing on STI and Public or Government expenditures on STI. A graphical explanation is presented in Figure 5.10.

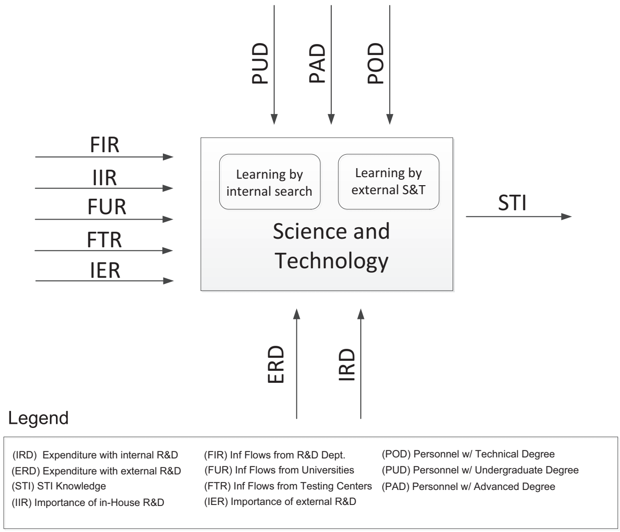

Figure 5.10: **Science and Technology Component Main Structure** - Source: Author

According to Figure 5.10, the Science and Technology component receives knowledge flows from the Human Capital component, namely personnel with undergraduate (PUD), advanced degrees (PAD) and other personnel (POD) engaged in STI activities. For learning by internal search, the component is fed by in-House R&D information flows (FIR), and by the degree of importance of in-House R&D (IIR), and also by the expenditures with in-house R&D (IRD). For learning by external advanced S&T, the component is fed by information flows coming from universities (FUR) and from testing and metrology centers (FTR), by the degree of importance (IER) and by expenditures on external R&D (ERD). The component receives all these flows and transforms them in STI knowledge, which outflows to the technological production component.

5.2.3 Technological Production Component

This component uses the knowledge generated in the science and technology component and transforms it into products of commercial use (Unger and Zagler, 2003) but also knowledge coming from other interactions outside the STI context. In this sense, technological production refers to the generation of innovation at firms from a process or product perspective (OECD, 2005).

From a conceptual perspective, this component is focused on the production of new or improved products and processes through the application of STI knowledge (coming from the Science and Technology component) and DUI knowledge. Doing, using and interacting (DUI) knowledge refers to knowledge created and acquired from activities other than STI (Jensen et al., 2007). As Jensen et al. (2007) explains, DUI-mode is acquired "on the job", as employees face problems and on-going changes and that results in a higher level of tacit knowledge. Such interactions constitute additional technological opportunities for firms in the innovation system which can be exploited by collaborating and interacting with other actors outside the traditional STI context (Castellacci, 2007).

Specifically, four latent variables from Bittencourt (2012) are taken out to be part of the Technological Production component: learning by doing, learning by interacting, learning to learn and learning by imitating.

Learning by doing refers to learning from hands-on-the-job, as employees become experienced and increase the efficiency of their tasks (Arrow, 1962). The second variable, learning by interacting is composed by three types of learning: learning with customers, learning with suppliers and learning with others (Bittencourt, 2012).

Learning with customers represents the type of learning when firms interact with their customers. Castellacci (2007) sustains that when firms build long term stable relationships with their customers it creates a positive effect on market competitiveness. For the same author, learning with suppliers is also an important source of learning by interacting especially in industries where the innovative process is strongly based on the acquisition of machinery and equipment, embodying more advanced technologies supplied by other industries. Finally, learning with other agents, represents learning processes from other external agents in which Bittencourt (2012) includes consulting firms, specialized conferences, etc.

The third learning type for DUI knowledge is learning to learn. This type of learning includes internal efforts of firms in training their human capital, which have been shown to have a positive effect on firm performance (Zack et al., 2009) and through external training expenditures, in professional training centers and alike.

The last learning type for DUI knowledge external acquisition is called learning by imitating, which Bittencourt (2012) describes as learning derived from imitating or reproducing innovations developed by other firms without cooperation with the innovator. Some mechanisms are included in this type of learning: patents and licenses, on the one hand and product imitation (through reverse engineering for example) on the other.

DUI knowledge and STI knowledge (from the Science and Technology component) build up what is called as the Innovative Capability of firms, the ability of a sector to produce and commercialize a flow of innovative technology over the long term (Furman et al., 2002; Lee, 2002). In this sense, the innovative capability of firms increases the product attractiveness of commercial products, which out flow to the Consumer Market component.

Figure 5.11 shows the summary of studies that identified a production component as part of an Innovation System.

Technological Production	
Denomination	**Authors**
Production System	(Hubner 1996; Lopez-Ortega 1997)
Industry and entrepreneurs	(Mohannak 1999; Etzkowitz and Leydesdorff 2000; Hsu 2005; Lee and von Tunzelmann 2005; Lee 2006)
Product design and development	(Galanakis 2006)
Industrial clusters	(Hung 2009)
Private sector	(Ahlqvist and Inkinen 2007)

Figure 5.11: **Technological Production Component** - Source: Author

From a modeling perspective, the component receives knowledge, information and financial inflows and transforms them into technological product and processes innovations, in the form of commercial products, which flow to the Consumer Market component.

As mentioned before, DUI knowledge is fed by four types of learning, in the following lines each of the learning types will be described. First, learning by doing is composed of information flows from internal departments other than the R&D department (FOP), of financial flows on expenditures with other technical preparations (EOP), and by the degree of importance of other technical preparations (IOP).

Second, learning by interacting, is composed of information flows from suppliers (FSU), from customers (FWC) and from other agents such as consulting firms and conferences (FWO). It is also fed by financial flows, from expenditures to acquire external knowledge (EEK), software (ESO), machinery and equipment (EME), and with others (EOT). The degree of importance of suppliers, customers and market are also taken into account: ISU and IWC.

Third, learning to learn is fed by information flows from professional training (FWT), expenditures with trainings (EWT) and the degree of importance of training (IWT).

Fourth, learning by imitating is composed of information flows from competitors (FCM), from patents and licenses (FPM), expenditures with imitating activities (EIM) and the degree of importance of other knowledge sources (IIM).

All four learning types build up DUI knowledge and together with STI knowledge form the innovative capability of the firm (CAP), which increase the amount to product attractiveness (PAT), the information flow that feeds market decisions in the Consumer Market component. Figure 5.12 shows a more detailed schematics of this component.

5.2.4 Consumer Market Component

Innovations get into the market to generate profit in firms (Lee, 2006). This component represents the dynamics of the consumer market (domestic and foreign) which receives technological innovations from firms and information from the attractiveness of new products.

Dynamics in markets determine many of the strategies related to technological innovation. As Castellacci (2007) sustains, different market structures determine different innovative behavior in sectors. Ease of entry of new competitors (domestic and foreign) for instance, determines the behavior as well as the size of the current market. As Malerba (2006) points out, market dynamics can be generated from technological innovation and also from captive demand and consumer learning which may stimulate technological change and the entry of new firms.

Moreover, Milling (1996) suggests that differences in the market structure also cause changes in management decision on investments on R&D

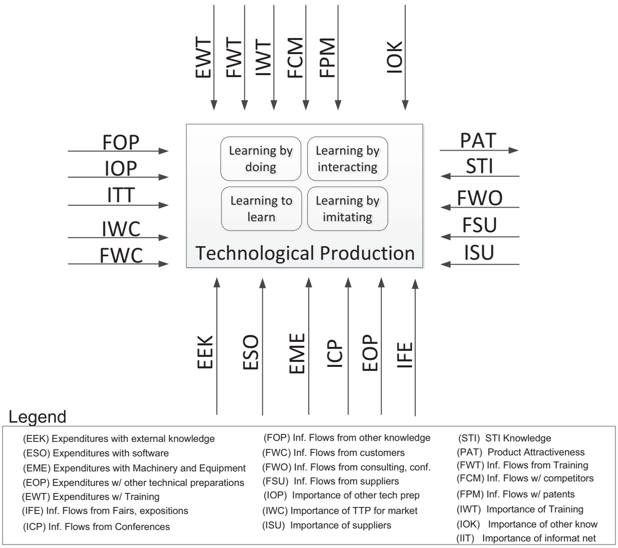

Figure 5.12: **Technological Production Component Main Structure** - Source: Author

and innovative activities and even changes in the rate of the diffusion of innovations.

Traditional literature on market dynamics and diffusion have suggested a basic structure, composed of a population of potential customers (potential adopters), customers (adopters) and an adoption rate, an innovation coefficient and an imitation coefficient, known as the Bass Model (Bass, 1969; Milling and Maier, 2009).

Additionally, the market component includes private and public agents whom are composed by the consumers of innovative products, both individual and corporate and finally, domestic consumers and international ones. Figure 5.13 shows several different denominations for the consumer market found on the literature.

Consumer Market	
Denomination	Authors
Product consumption system	(Hubner, 1996)
Economic competence	(Johannessen et al., 1997)
Value-added system	(Lopez-Ortega, 1997)
Consumer market (domestic and/or international)	(Hung, 2009; Janszen & Degenaars, 1998; Shyu et al., 2001)
Product Market	(Galanakis, 2006; T. L. Lee, 2006; T. L. Lee & von Tunzelmann, 2005)

Figure 5.13: **Consumer Market Component** - Source: Author

From a modeling perspective, the consumer market component receives a degree of potential success of innovations as defined as product attractiveness (PAT) information flows as well as the expenditures with the introduction of technological innovations into the market (EWC) and with the degree of importance of the introduction of technological innovation into the market (IWC). On the other hand, the market component feeds back the technological production component by feeding it with information flows from customers (FWC), an important source of information for the production of innovations (Castellacci, 2007). As mentioned before, the market structure defines other dynamics within the innovation system, specifically, by generating a degree of attractiveness for the overall sector (as compared with other sectors), which defines decisions in the financing and funding component.

Market structure also generate a certain level of profitability which defines decisions on entry of newcomers, opportunity levels, stability of current innovators and reinvestments on overall innovative activities (Malerba and Orsenigo, 1993; Castellacci, 2007). It also defines decisions of private firms which desire to invest on the sector and influences government decisions on maintaining, reducing or increasing expenditures on the sector, on promoting incentives, etc. Figure 5.14 shows the schematics of this component.

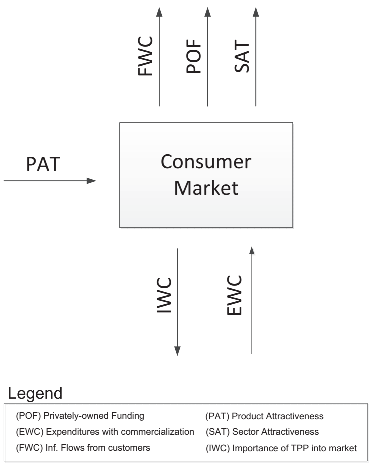

Figure 5.14: **Consumer Market Component Main Structure** - Source: Author

5.2.5 Human Capital Component

Talented people generate the new ideas that drive innovation and represent the stock of embodied knowledge which performs scientific research in universities and research institutes and innovative activities in firms.

Human capital is the firm's collective capability to solve problems by using its employees' individual knowledge (Bontis, 1998), that is accumulated mainly through learning by doing, learning to learn processes, part of DUI knowledge and through learning by internal search, part of STI knowledge. Human capital is also important for acquiring external knowledge and to make use of it in adequate manner, such a property, known as absorptive capacity (Cohen and Levinthal, 1990).

The degree of cumulativeness of previous knowledge - the extent to which current innovative activity is build up from previous knowledge (Castellacci, 2007) - is also linked with the level of absorptive capacity, since the employees ability to acquire external knowledge depends on the amount of previous internal knowledge.

Education levels are also important to innovative activity, since current literature has suggested a relationship between education level and the creation of new knowledge, and also the amount of innovative activities fostering demand for skilled human capital (Castellacci, 2007). In this sense, human capital skills do not only depend on education levels, but also on periodical training activities undertaken by innovative firms. These training activities refer to training in specific strands of knowledge which are also specific to firm's innovative activities.

In this sense, the Council of Competitiveness (COC) suggests that governments (national and regional) must ensure that firms and employees have access to education (technical, undergraduate and graduate) and training programs for continuous learning and skill development (COC, 2005). Figure 5.15 shows some of the definitions found on the literature.

Human Capital	
Denomination	**Authors**
Labor system	(Lopez-Ortega, 1997)
Workforce	(Shyu et al., 2001)
Human Resource Development	(Hung, 2009; T. L. Lee, 2006; T. L. Lee & von Tunzelmann, 2005; Stamboulis, 2008)

Figure 5.15: **Human Capital Component** - Source: Author

From a modeling perspective, the component receives funding for training activities (EWT) from firms with the aim to improve their employees' competencies. It also receives funding from private and public agents investing in graduate and undergraduate education (EHE) and outflows qualified human capital with technical (POD), undergraduate (PUD) and advanced degrees (PAD) engaged in R&D activities in the science and technology component.

On the other hand, Human Capital contributes to the innovation system, with qualified staff with undergraduate and advances degrees, which are the enablers and creators of innovations (See Figure 5.16.

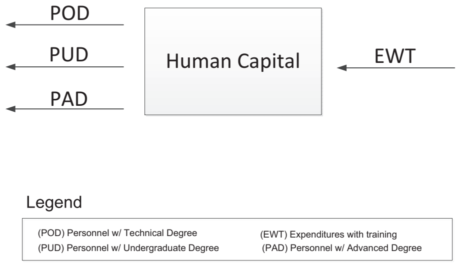

Figure 5.16: **Human Capital Component Main Structure** - Source: Author

5.2.6 Synthesis

Based on the review results of Section 5.1, a new modeling framework was proposed, synthesizing the main components and linkages of innovation systems that have been proposed by previous studies. The modeling framework is a macro-structure that links five major components. The aim of the modeling framework is to help in designing and instantiating more quantitative-oriented models of innovation systems, thus it is argued that it serves to represent any type of innovation system (national, regional, sectoral, technological, etc.) at the macro level.

Specifically, the new designed framework highlights that any innovation system may be regarded as composed by a Financing and Funding component, a Science and Technology component, a Technological Production component, a Consumer Market component and a Human Capital component. In addition, the framework described how such components are linked to each other, by means of different types of learning activities: learning by internal search learning from external advanced S&T, learning by doing, learning by imitating, learning by interacting and learning to learn. It also described how knowledge is accumulated and identified two specific types of knowledge: science, technology and innovation (STI) knowledge and doing, using and interacting (DUI) knowledge.

Thus, the framework describes in a detail way how knowledge and learning processes are linked with and affect the innovation system, from a conceptual perspective, in other words, it links knowledge and learning with the innovation system from a static and descriptive perspective. In the next section, the components and links from the framework are structured in causal loops, which confer the first level of dynamicity to the model.

5.3 Causal Loop Model Design

The model building phase started with the design of the causal loop model, which was based on literature review and on the modeling framework of Section 5.2. The causal loop model, also known as causal loop diagram (CLD), help in portraying the relationships among the identified factors in order to illustrate and explain the dynamics of the system (See Section . The causal loop model developed for this dissertation contains thirteen causal loops, which will be explained in the following Sections. Figure 5.17 shows the complete model which includes 8 reinforcing loops (represented by the R letter) and 5 balancing loops (represented by the B letter).

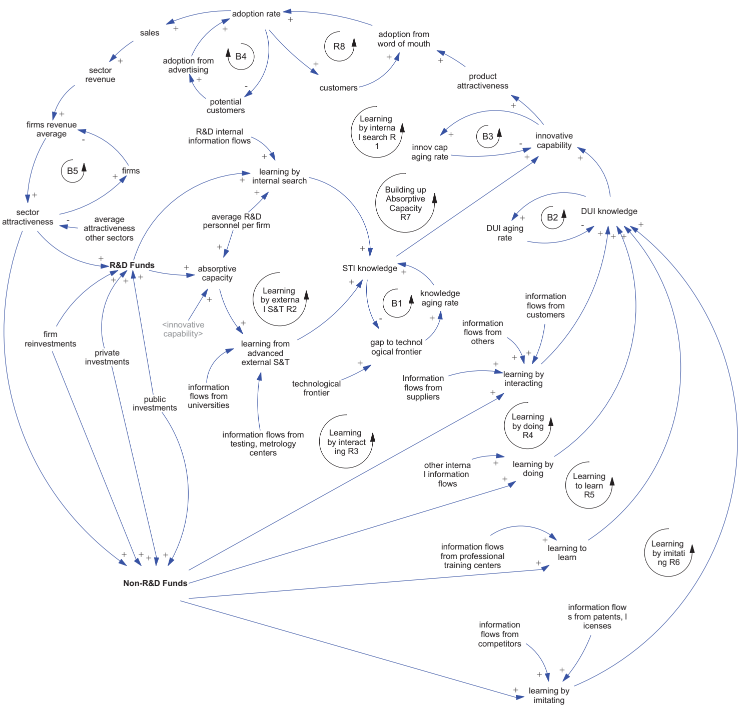

Figure 5.17: **Complete Causal Loop Model for Innovation Systems -** Source: Author

The causal diagram in Figure 5.17 represents the main structure of the software sectoral innovation system in Brazil, composed by several types of learning processes which interact and build up the innovative capability needed to produce and to introduce technological innovation into the market. From the results of technological innovations on the market, the systems feeds back by using financial, human and knowledge flows.

The software sector in Brazil uses several mechanisms to create knowledge (internal mechanisms) and to acquire knowledge (external mechanisms). Literature defines such mechanisms as learning processes which are used by firms to produce STI knowledge and DUI knowledge (See Section 5.2). Moreover, specialized literature has suggested that learning activities can be characterized as inflows through which knowledge is created and stored in the form of a knowledge stock the level of accumulated knowledge over a period of time (Bontis et al., 2002; Vera and Crossan, 2003).

Most of the reinforcing loops identified in the following Sections converge with that literature stream and are classified basically, by the type of learning process used by firms and by the intensity of its use. In addition, other reinforcing loops were identified in relation to building up absorptive capacity, which is a process that depends not only on learning by also on the cumulativeness of previous internal knowledge and on the ability to successfully internalize external knowledge (Cohen and Levinthal, 1990); and in relation to market dynamics as defined by the literature of innovation diffusion (Bass, 1969). On the other hand, balancing loops were specific to aging dynamics of knowledge, innovative capability, market and firms. In the following Sections each loop will be described.

5.3.1 Reinforcing Loops

R1 Loop: Learning by internal search

As described in Section 5.2, STI knowledge is composed of two learning processes: learning by internal search and learning by external S&T. The first loop depicts the reinforcing behavior produced by learning by internal search processes for building up STI knowledge, as shown in Figure 5.18.

The positive signs in Figure 5.18 mean the positive relationship between the three variables R&D Funds, average R&D personnel per firm and internal information flows from the R&D Department with learning by internal search. Literature, as described in previous Sections, demonstrates that R&D funds increase the supply of internal sources of knowledge through in-House R&D activities; R&D personnel and information flows from the

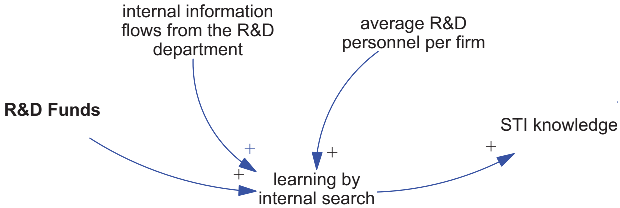

Figure 5.18: **Loop R1 - Learning by internal search and STI knowledge** - Source: Author

internal R&D department are also inputs to learning by internal search, (Jensen et al., 2007; Tayaran, 2011). In the Software Sector in Brazil, in-house R&D activities are the most important source of firm expenditure related with innovative activities in general.

STI knowledge in turn, builds up the innovative capability of firms and therefore, the broad innovative capability of the software sector (Figure 5.19). Innovative capability is the process in which new STI knowledge is internalized into the routines of firms and the ability of the sector to produce and commercialize a flow of innovative technology over the long term (Furman et al., 2002; Lee, 2002).

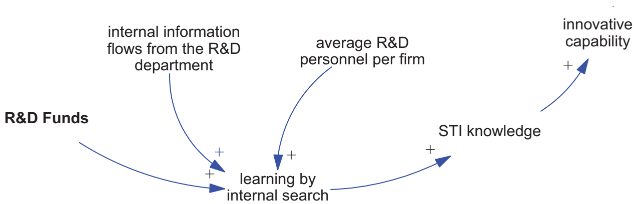

Figure 5.19: **Loop R1 - Learning by internal search, STI knowledge and Innovative Capability** - Source: Author

Since the innovative capability is the measure of producing and commercializing new technologies into the market, it causes a positive impact on product attractiveness, as shown on Figure 5.20. Product attractiveness is a latent variable that tries to synthesize the overall attractiveness of software products to the market.

Product attractiveness in turn, increases the probability of product

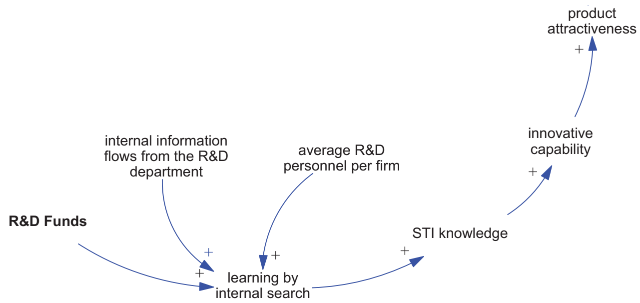

Figure 5.20: **Loop R1 - Innovative Capability and Product Attractiveness** - Source: Author

adoption from a process known as word of mouth, which represents social exposure between actual customers and new customers and imitation behavior (Sterman, 2000). In addition, there is a second process of product adoption, known as adoption from advertising, which will be explained in Loop B4. Figure 5.21 shows the positive effect of product attractiveness on the adoption of new products by word of mouth.

As mentioned before, adoption from word of mouth refers to social exposure and imitation, therefore the higher the adoption from word of mouth, the higher the adoption rate. Software products usually have a short life cycle, for reasons such as the entry of a larger number of countries exporting software, the advancement of technological frontiers to mention a few (See Appendix 2). Thus, literature on diffusion of innovation dynamics suggests a positive link between adoption from word of mouth and the adoption rate (Bass, 1969; Sterman, 2000). Figure 5.22 shows the positive relationship between adoption from word of mouth and adoption rate.

The adoption rate of technological innovation defines the speed at which new or improved software products are diffused across the market. Then, this process increases the amount of sales of software products, as shown in Figure 5.23. Since the software sector is knowledge intensive, the amount of software sales is dependent of exogenous factors as well, such as the international economic environment, the ratio between domestic and international market, etc. The Brazilian software sector is highly domestic, including mainly software solutions to other sectors in the country (See

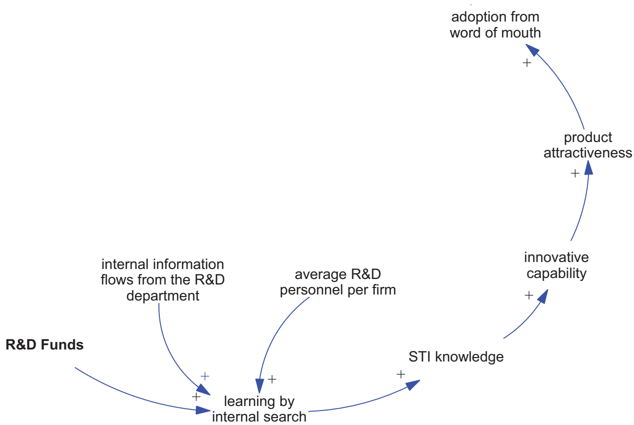

Figure 5.21: **Loop R1 - Product Attractiveness and word of mouth** - Source: Author

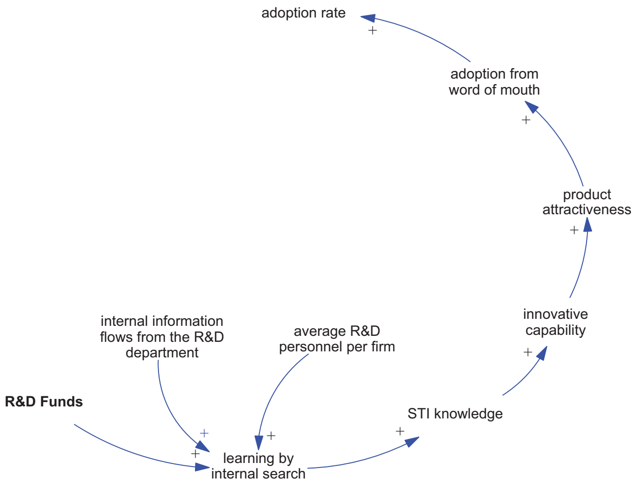

Figure 5.22: **Loop R1 - Word of Mouth and Adoption Rate** - Source: Author

Appendix C).

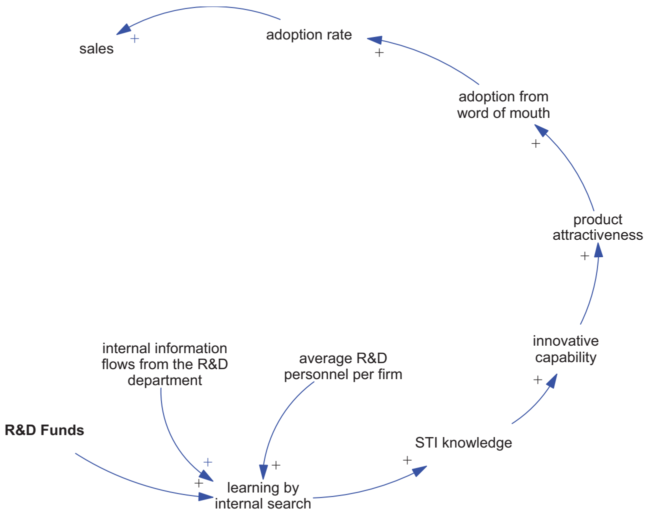

Figure 5.23: **Loop R1 - Adoption Rate and Sales** - Source: Author

The amount of software sales increases the total sector revenue, which is composed of the total amount of software revenue in the country. As discussed in Appendix C overall revenue of the software sector has shown an increasing trend, ultimately suggesting that the market has adopted a larger number of software products, increasing sales and therefore the sector revenue. Figure 5.24 shows the positive relationship between sales and sector revenue.

Sector revenue can help in estimating the average revenue per firm, which can serve as an indicator of sector attractiveness. This is especially useful in the software sector, since the various types of software firms, the different firm's size and the differences in revenue per firm make a direct measurement extremely difficult.

Figure 5.25 shows the positive relationship between sector revenue and firms revenue average. It is worth noting, that in Loop B5, the effect of firms revenue average will be also analyzed.

The average revenue per firm increases the sector attractiveness as long as the average revenue increases as well. Sector attractiveness is a latent variable that seeks to synthesize the overall attractiveness of the sector when compared with the overall attractiveness of other sectors.

In this sense, Figure 5.26 shows the relationship between sector attrac-

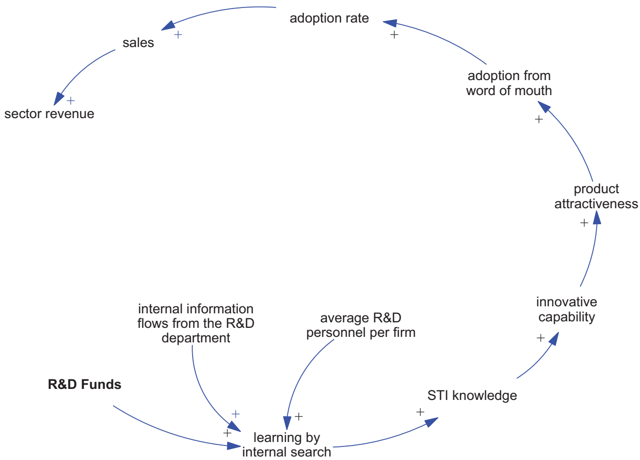

Figure 5.24: **Loop R1 - Sales and Sector Revenue** - Source: Author

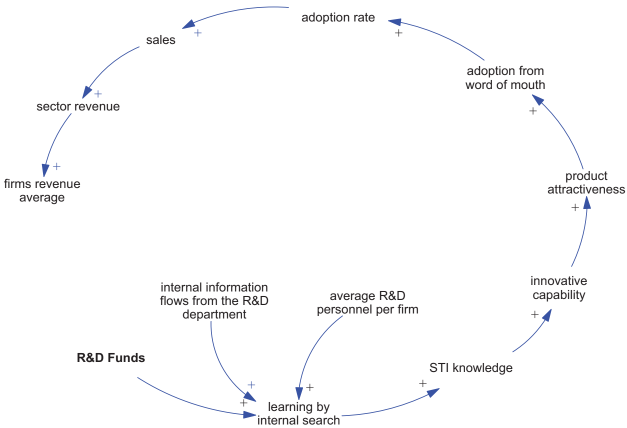

Figure 5.25: **Loop R1 - Sector Revenue and Average revenue per firm** - Source: Author

tiveness with R&D Funds, closing up the loop R1, naming it "Learning by internal search".

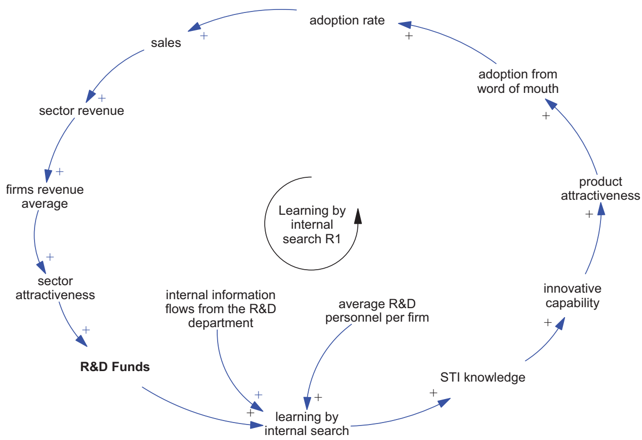

Figure 5.26: **Loop R1 - Average revenue per firm and Sector Attractiveness** - Source: Author

Accordingly, sector attractiveness can be used as a performance measure in relation to other sectors. Previous literature on innovation systems has argued that each innovation system accounts for a performance level, which thus can be used to compare distinct innovation systems and help actors in designing and formulating public policy, in investment decisions and so on (Niosi, 2002).

The specific importance of the sector attractiveness variable for the software sector in Brazil is related mainly to the size of investment which is feed back into the system after been compared with the attractiveness of other sectors. This decision is used by firms itself, which have to decide on whether or not to invest more on their learning processes by internal search; by the private sector, which has to make the same decision by comparing their rate of return against the rate of return of other sectors; and finally, the government as well, which has to decide whether to continue investing on the software sector or not, by means of investing on fostering other sectors.

Even though, data on this issue is highly difficult to obtain, some current behavior can be observed. As described in Appendix C, several new policies have been created in the last years to foster the Brazilian IT Sector in general and the Brazilian Software Sector especially, suggesting that for different actors in the sectoral system, the overall sector attractiveness has been higher than the one of other sectors. In fact, the IT Sector is one of the strategic sectors the Brazilian Government has been supporting over the last years.

R2 Loop: Learning from external S&T

The second loop (R2) represents the learning process by external search in advanced S&T, as described in Section 5.2 In this sense, learning by external S&T is the second type of learning for STI knowledge, through the acquisition of external knowledge (Bittencourt, 2012). (Figure 5.27).

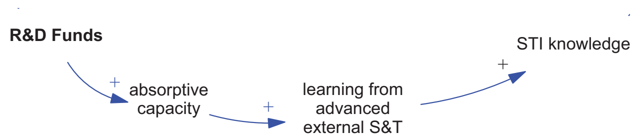

Figure 5.27: **Loop R2 Learning from advanced external S&T and STI Knowledge** - Source: Author

Similar to R1, learning by external S&T starts from the amount of R&D Funds that are provisioned by the firms reinvestment share, by the investment from the private sector and from the public sector as well. In this sense, R&D Funds have an initial effect on the overall absorptive capacity of firms. As has been discussed in previous literature, the absorptive capacity is the ability of a firm to internalize externally acquired knowledge in order to use it in innovative activities (See Section 5.2).

It is worth mentioning that absorptive capacity is not only dependent of R&D funds, but also of the cumulativeness of previously acquired and created knowledge, a latent variable which was named as innovative capability in this dissertation, this effect however will be described later in the R7 Loop Section.

Absorptive capacity increases as R&D Funds increases, and at the same time, the increase in absorptive capacity produces an increase in learning from advanced external S&T. As mentioned before (Section 5.2), learning from advanced external S&T refers to the degree at which information flows between the firm and advanced S&T institutions, such as Universities and Testing Centers, contribute with the innovation process. Finally, learning from advanced external S&T is related in a positive way with the increase of STI knowledge. This structure can be observed in Figure 5.28.

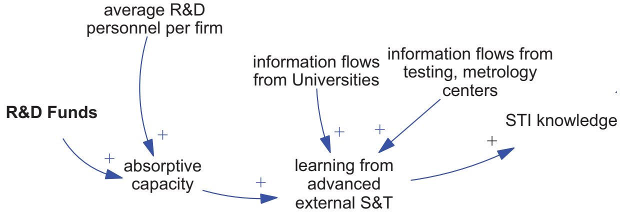

Figure 5.28: **Loop R2 R&D Funds, Absorptive Capacity and STI Knowledge** - Source: Author

As described in Loop R1, STI knowledge increases the innovative capability of the sector. In this sense, learning from advanced external S&T also increases the size of STI knowledge and therefore the size of innovative capability. Figure 5.29 shows the positive relationship between STI knowledge and innovative capability.

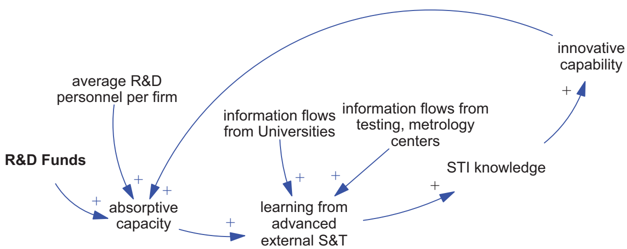

Figure 5.29: **Loop R2 Learning from advanced external S&T, STI Knowledge and IC** - Source: Author

An additional loop (R7) is found between innovative capability and absorptive capacity as shown in Figure 5.30. This loop will be described in the Section designed for R7.

Following the structure from R1, this loop also builds upon innovative capability through the previously described variables, closing the loop as sector attractiveness increases R&D Funds. Figure 5.31 presents the completed R2 loop, named as Learning from external S&T and also the structure of learning by internal search.

In Figure 5.31 some interesting insights can be made. First, the size of

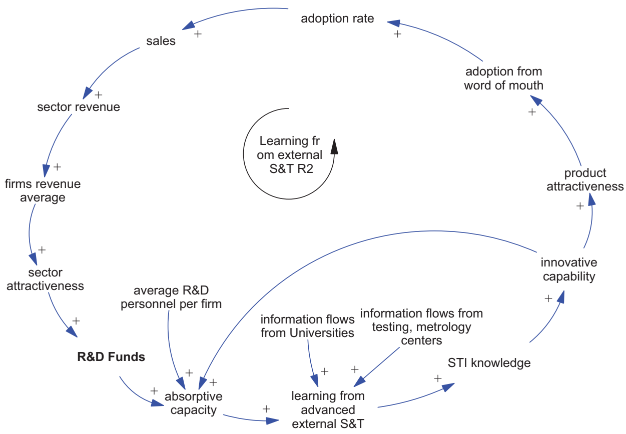

Figure 5.30: **Loop R2 Learning from advanced external S&T and Innovative Capability** - Source: Author

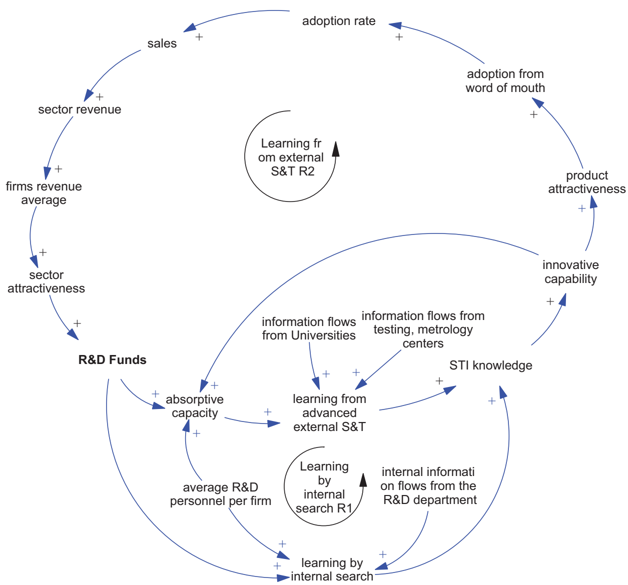

Figure 5.31: **STI Knowledge through Loop R1 and Loop R2** - Source: Author

R&D departments has an influence on both internal and external learning. For internal learning, the influence is clear, in the sense that it is the R&D personnel from the R&D Department of firms whom are the ones performing internal search through in-house R&D. For the case of external R&D, the effect is indirect, in the sense that in order to build up absorptive capacity, there is a path dependency on the previous knowledge stored on the firm, thus, the R&D personnel contributes with their previous knowledge, to build the absorptive capacity of the firm.

R3 Loop: Learning by interacting

The third loop is referred the process of learning by interacting. Differently from R1 and R2, this loop builds another type of knowledge, known as DUI knowledge (See Section 5.2). The structure is basically very similar to the structures of R1 and R2: Non-R&D Funds (which are the sum of firm reinvestments, private investments and public investments) increase the level of learning by interacting, which in turn increase the level of DUI knowledge. Figure 5.32 shows the basic initial structure for Loop R3.

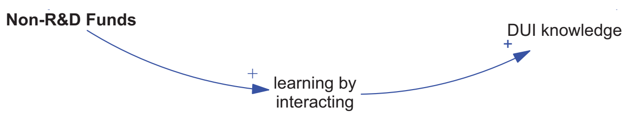

Figure 5.32: **Loop R3 Learning by interacting and DUI Knowledge** - Source: Author

As argued in Section 5.2, DUI knowledge is the second type of knowledge that builds up innovative capability, besides STI knowledge. In this sense, there is also a positive relationship between DUI Knowledge and innovative capability as shown on Figure 5.33.

DUI knowledge in the software sector can be represented by the efforts made by firms in creating and acquiring knowledge other than from STI. Thus, interactions with other actors in the sectoral system, such as suppliers, customers and others may increase the likelihood of acquiring external knowledge (Niosi, 2002). For the case of the Software Sector in Brazil, the higher importance of innovative activities was given to the acquisition of machinery and equipment in the period 2003-2005 and even though it decreased during 2006-2008, it still remained as the second most important

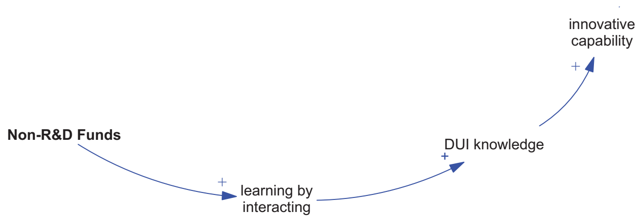

Figure 5.33: **Loop R3 Learning by interacting and Innovative Capability** - Source: Author

source (See Appendix C). Other sources, important as well, are identified in Figure 5.34 as information flows from customers and from other actors.

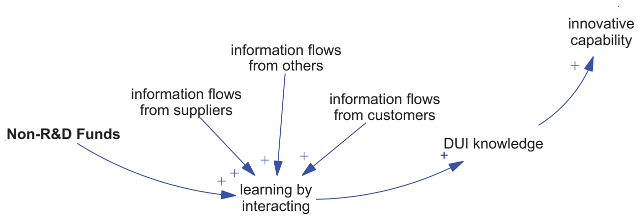

Figure 5.34: **Loop R3 Learning by interacting, DUI and innovative capability** - Source: Author

Following the logic of the previous loops, R3 also increases product attractiveness, adoption from word of mouth, adoption rate, sales, sector revenue, firms revenue average and ultimately sector attractiveness, forming the third reinforcing loop, named as Learning by Interacting (Figure 5.35).

R4 Loop: Learning by doing

The fourth loop represents the structure of learning by doing processes on the software sector. Similarly to R3, non-R&D Funds are directed to learning by doing activities, which ultimately lead to an increase in DUI knowledge, as shown on Figure 5.36.

Learning by doing, as defined in Section 5.2, is the process at which employees accumulate knowledge through hands-on-the-job activities, and one of the most important mechanisms for the creation of tacit knowledge

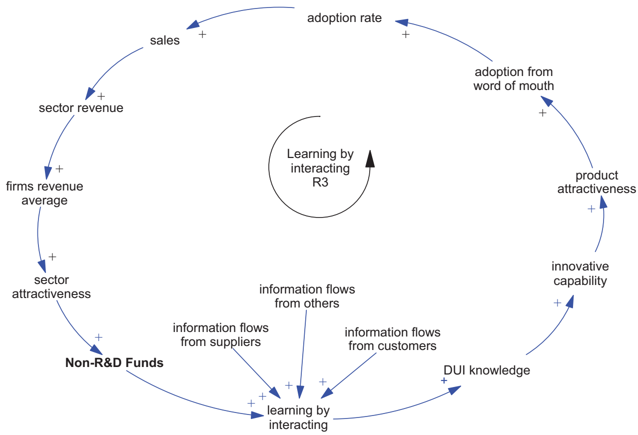

Figure 5.35: **Loop R3 Learning by interacting and sector attractiveness** - Source: Author

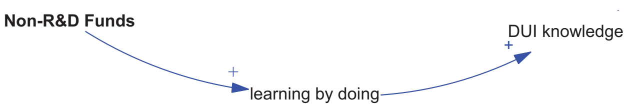

Figure 5.36: **Loop R4 Learning by doing and DUI Knowledge** - Source: Author

(Nonaka, 1994). Thus, learning by doing is built through the interaction with departments within the firm other than the R&D department as shown in Figure 5.37. The relationship between DUI knowledge and innovative capability is again depicted in R4 Loop.

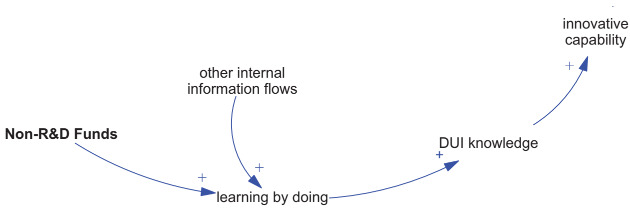

Figure 5.37: **Loop R4 Learning by doing and innovative capability** - Source: Author

As DUI knowledge increases, innovative capability increases as well and following the structure of previous loops, several variables until sector attractiveness closes the loop by helping actors within the sectoral system in deciding how much to invest on non-R&D Funds. Figure 5.38 shows the complete structure of Loop R4, named Learning by Doing.

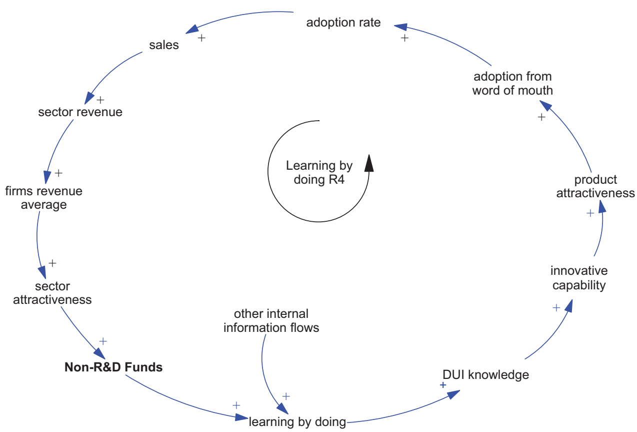

Figure 5.38: **Loop R4 Learning by doing and sector attractiveness** - Source: Author

R5 Loop: Learning to learn

Learning to learn represents the efforts, made by firms, in training their human capital (Section 5.2). As the previous loops R3 and R4, learning to learn contributes to build up DUI knowledge as well. Figure 5.39 shows the basic structure of Loop R5.

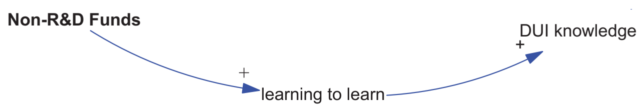

Figure 5.39: **Loop R5 Learning to learn and DUI Knowledge** - Source: Author

In addition to the expenditures on training activities, learning to learn is feed by the incoming information flows from those Training Centers. The main difference between learning to learn and learning from advanced S&T is that in learning to learn, the channels of training are more professional-oriented rather than academic-oriented training found on Universities and so on. Figure 34 shows the inclusion of information flows from professional training centers and its positive effect on learning to learn. Similarly to previous loops, learning to learn also contributes to increase the innovative capability of firms within the software sector, also shown in Figure 5.40.

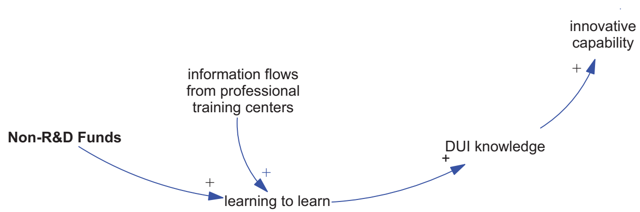

Figure 5.40: **Loop R5 Learning to learn and innovative capability** - Source: Author

Sector attractiveness closes the loop R5, named Learning to learn and shown, in its complete form in Figure 5.41.

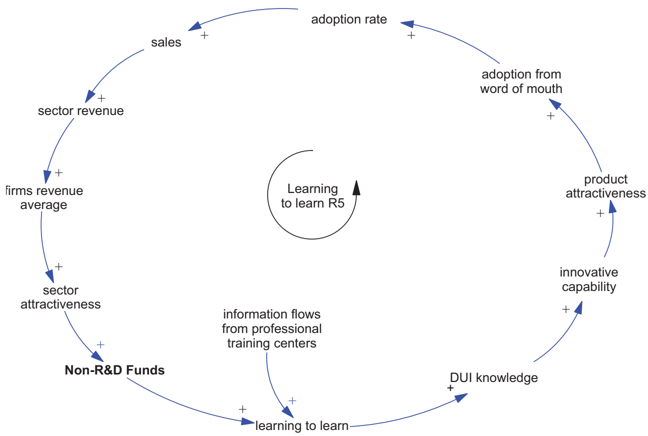

Figure 5.41: **Loop R5 Learning to learn and Sector Attractiveness** - Source: Author

R6 Loop: Learning by imitating

The sixth loop, learning by imitating is related with searching on other actors within the sectoral system and in using them as sources of innovative activities. Figure 5.42 shows the basic structure of loop R6: non-R&D funds are positively related with learning by imitating, and the latter is positively related by DUI knowledge.

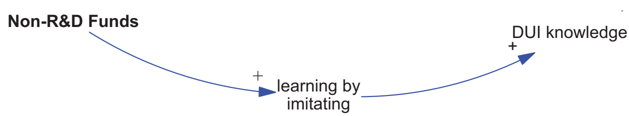

Figure 5.42: **Loop R6 Learning by imitating and DUI knowledge** - Source: Author

In this type of learning, non-R&D funds are destined specifically to look for sources of innovation from competitors and from intellectual property in the form of patents, licenses and other. Previous literature has described the role of imitators within the development of new products and technologies and their effects on innovation diffusion (Milling, 1996). Figure

5.43 shows the inclusion of information flows from competitors and from patents and licenses on learning by imitating, it also shows the relationship between DUI knowledge and innovative capability.

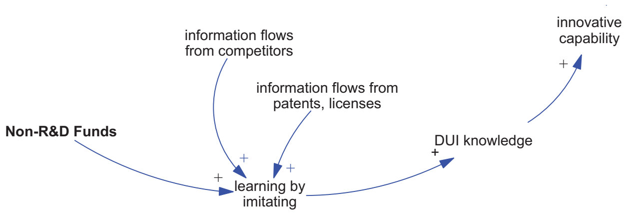

Figure 5.43: **Loop R6 Learning by imitating and innovative capability** - Source: Author

Learning by imitating closes the loop with sector attractiveness and its positive effect on non-R&D funds as shown on Figure 5.44.

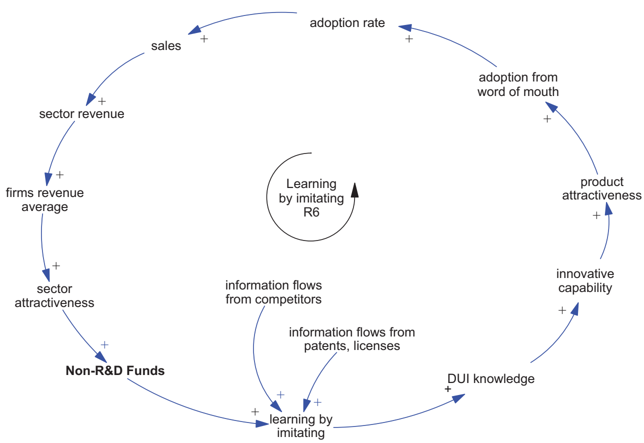

Figure 5.44: **Loop R6 Learning by imitating and sector attractiveness** - Source: Author

All four loops (R3, R4, R5 and R6) are linked together to build up DUI knowledge. Figure 5.45 shows all four loops and their interactions.

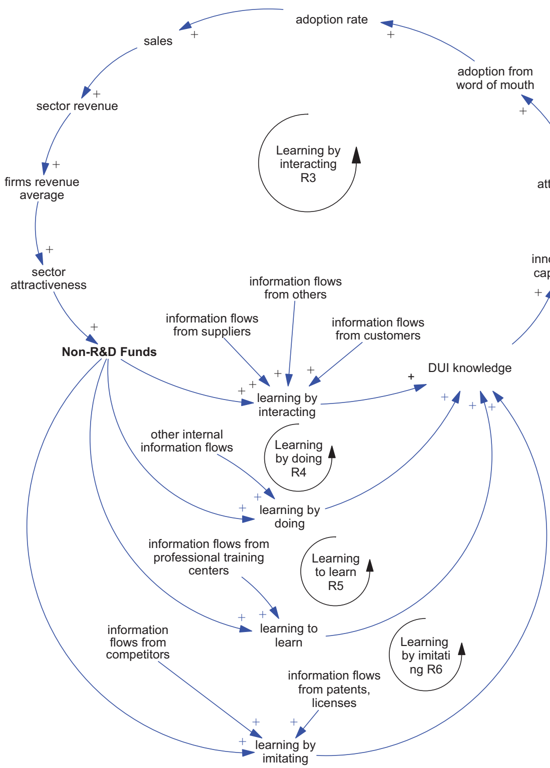

Figure 5.45: **Loop R3, R4, R5 and R6** - Source: Author

R7 Loop: Building up absorptive capacity

Absorptive capacity is one of the key processes inside an innovation system. Despite interacting with different types of learning, it enables firms to recognize and assimilate valuable knowledge, transform it and apply it into new products (Tayaran, 2011).

Recent work on the field of absorptive capacity has related it with innovative capability as a co-evolutionary process. Coevolution thus, may be described as a reinforcing loop, in which the growth of innovative capability increases as absorptive capacity increases as well, as shown in Figure 5.46.

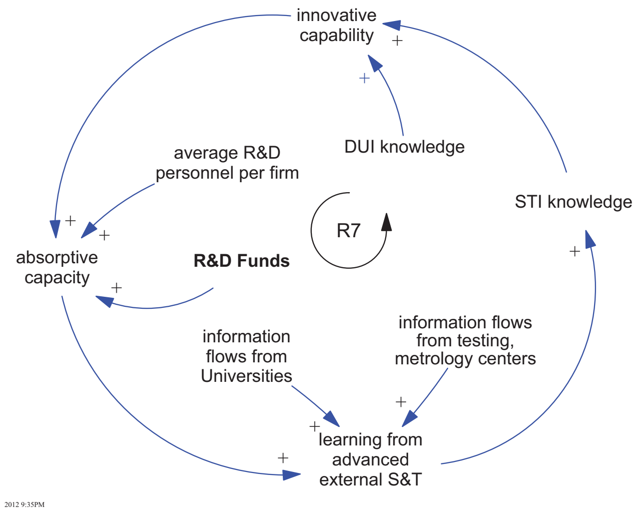

Figure 5.46: **Loop R7 Building up Absorptive Capacity** - Source: Author

As absorptive capacity increases, learning from advanced external S&T increases, and so STI knowledge. Then both, STI knowledge and DUI knowledge contribute to increase the amount of innovative capability.

R8 Loop: Gaining more customers

This reinforcing loop, R8, is related with market dynamics and innovation diffusion literature. It basically relates the level of innovative capability with the degree of product attractiveness and with the rate of adoption from word of mouth. As previously described, the adoption from word of mouth process increases the adoption rate. The rate of adoption increases sales but also increases customers. As more customers are adopted, the effect of adoption from word of mouth is larger as well, i.e. more customers mean a higher contact rate, which is basically the process of "contagion" as seen on innovation diffusion dynamics (Sterman, 2000).

Figure 5.47 shows the basic structure described before.

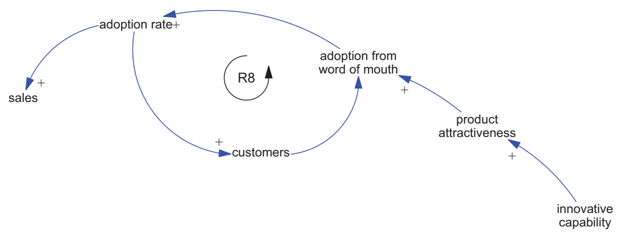

Figure 5.47: **Loop R8 Innovative Capability and Adoption from word of mouth** - Source: Author

5.3.2 Balancing Loops

B1 Loop: STI Knowledge Aging

Balancing loops are also present in the structure of innovation systems. Particularly, in high technology sectors such as the software sector, the speed at which knowledge "ages" is higher. Literature also supports the notion of "knowledge aging" in the sense of losing knowledge that was previously accumulated in the firm. There are processes at which knowledge is lost due to employee attrition among others, known as organizational forgetting (Rao and Argote, 2006), and others at which the firm is unable to integrate new knowledge, by the deterioration of accumulated knowledge or even by voluntary unlearning, known as organizational unlearning (Martin de Holan, 2011). Knowledge aging represents the process at which knowledge stored in the firm will be "economically" useful, as compared to the new knowledge being created or acquired.

All these subtypes are included in the variable knowledge aging rate which is positively linked with STI knowledge. STI knowledge in turn, reduces the existing gap to the technological frontier, i.e. the greater the STI knowledge, the smaller the gap. On the other hand, if the gap to the technological frontier is large, so it will the aging rate, meaning that knowledge that the firm possess will age more rapidly since it is already way behind the technological frontier. Finally, the knowledge aging rate will increase the need for STI knowledge, closing the loop, as shown on Figure 5.48.

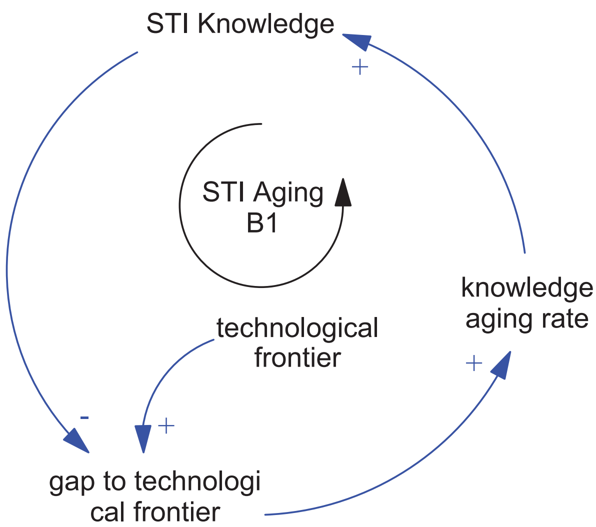

Figure 5.48: **Loop B1 STI Knowledge Aging** - Source: Author

B2 Loop: DUI Knowledge Aging

Similarly to Loop B1, DUI knowledge also "ages", following the same processes of organizational forgetting and unlearning previously described. Figure 5.49 shows the balancing loop B2.

B3 Loop: Innovative Capability Aging

The third balancing loop (B3) follows the same structure described in the previous loops B1 and B2, meaning that the innovative capability of the software sector can also be diminished by the process of "aging". Thus, for a sectoral system with superior performance, the reinforcing loops producing innovative capability should be dominant over the aging loop. Figure 5.50 shows the main structure of B3.

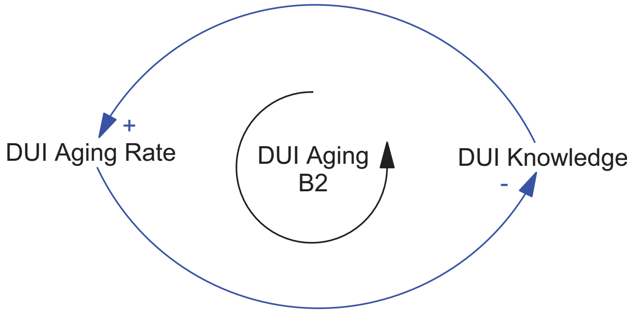

Figure 5.49: **Loop B2 DUI Knowledge Aging** - Source: Author

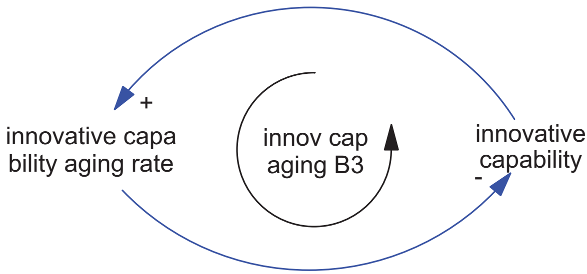

Figure 5.50: **Loop B3 Innovative Capability Aging** - Source: Author

B4 Loop: Market saturation

The market saturation loop is related with previous loops describing market dynamics and innovation diffusion. Figure 5.51 shows the negative influence of adoption rate on potential customers, i.e. the higher the adoption rate is, the less potential customers will be.

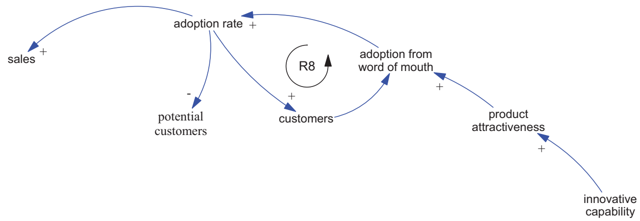

Figure 5.51: **Loop B4 Adoption Rate and Potential Customers** - Source: Author

Potential customers, on the other hand, has a positive relationship with the adoption from advertising process. The higher the number of potential customers, the higher will be the number of new customers by advertising activities. In the Brazilian software sector, advertising activities, named as expenditures on the introduction of technological innovations into the market represented an 8% of total expenditures on innovative activities for the 2003-2005 period and a 5.5% for the 2006-2008 period. Figure 5.52 shows the positive relationship between potential customers and adoption from advertising.

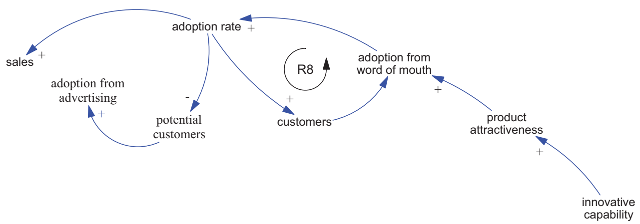

Figure 5.52: **Loop B4 Potential Customers and Adoption from Advertising** - Source: Author

Adoption from advertising increases the adoption rate, closing the balancing loop B4 as shown on Figure 5.53.

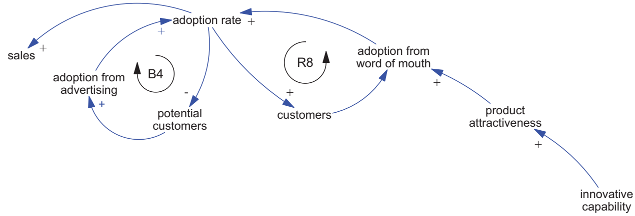

Figure 5.53: **Loop B4 Adoption from Advertising and Adoption Rate** - Source: Author

B5 Loop: Firms Saturation

The balancing loop B5 relates the sales of software products, the overall sector revenue, the average revenue per firm and the overall sector attractiveness. Elsewhere it was suggested that sector attractiveness may be used as a performance indicator of the sectoral system, which could be used to assess its relative performance and compare it with other sectoral systems. Figure 5.54 shows the positive causal links between sales and sector attractiveness.

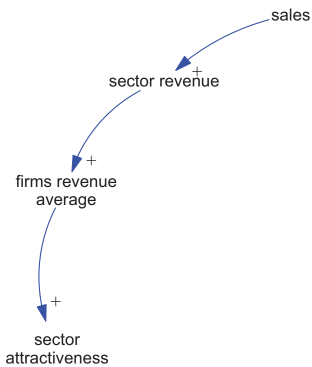

Figure 5.54: **Loop B5 Sales and Sector Attractiveness** - Source: Author

The sector attractiveness however, is a comparative measure as well, which is defined when comparing the average revenue per firm with the average attractiveness of other sectors. The higher the difference in favour to the average revenue per firm, the higher will be the overall attractiveness of the sector.

Moreover, the level of the sector attractiveness defines the level of investments in future innovative activities by firms itself, by the private sector, which is interested in investing in the most profitable sectors, and also by the public sector, which defines how much funding it will give to specific sectors. Figure 5.55 shows the negative relationship between the sector attractiveness and the average attractiveness of other sectors.

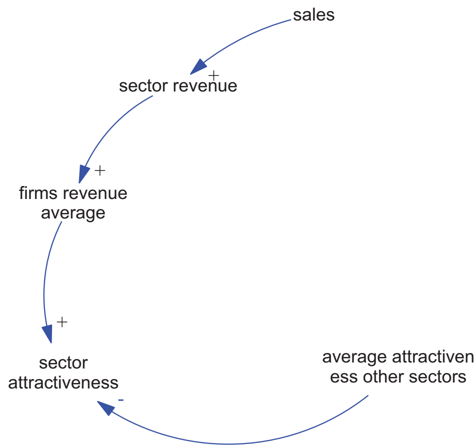

Figure 5.55: **Loop B5 Sector Attractiveness and Average attractiveness other sectors** - Source: Author

The higher the sector attractiveness, the higher will be the desire of new firms in entering the software market. In the 2000s, a large number of firms entered the global software market, especially internet firms, which afterwards followed a market and firm saturation effect, known as the dotcom or internet bubble. Sector attractiveness is also related with opportunity and appropriability conditions (Malerba and Orsenigo, 1993; Castellacci, 2007, 2008) which determine a context-specific environment in which sectoral dynamics take place.

Figure 5.56 shows the positive relationship between the sector attractiveness and the number of firms in the sector.

As the number of firms increases in the market, the average revenue per firm will tend to decrease, even if there are increasing rates of return, at some level, the amount of firms will saturate the market and decrease overall revenues and therefore revenue per firm. As mentioned before, decisions on investments are based on the relative value of sector attrac-

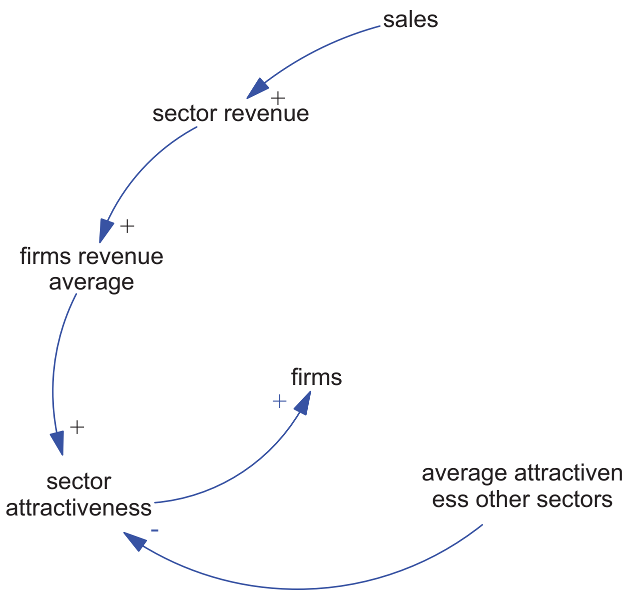

Figure 5.56: **Loop B5 Sector attractiveness and Firms** - Source: Author

tiveness, which influence the amount of funding destined to R&D and to non-R&D activities.

Figure 5.57 shows the negative relationship between firms and average revenue per firm, producing the balancing loop B5, named as Firms Saturation.

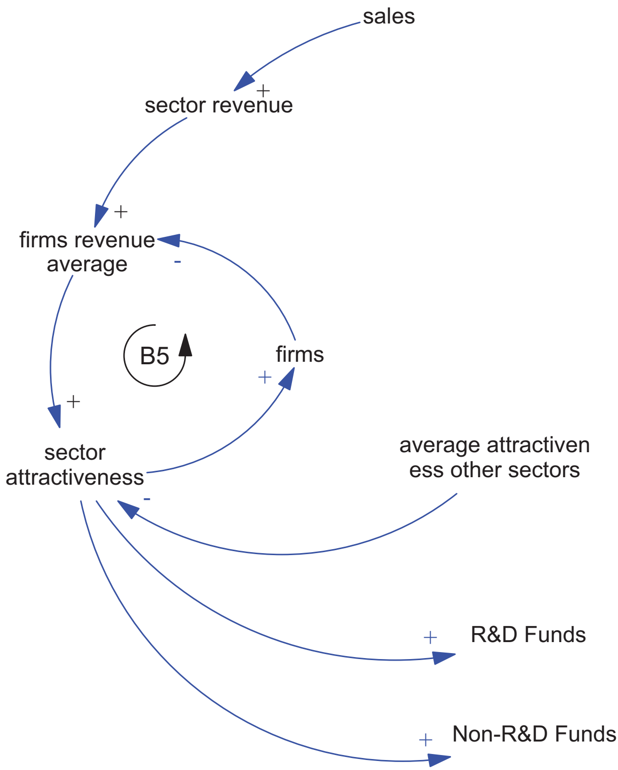

Figure 5.57: **Loop B5 Sector Attractiveness, firms and firms revenue average** - Source: Author

5.3.3 Synthesis

This Section has described the causal loops model that helps in observing the dynamic relationship between the various variables in the system. The modeling framework of Section 5.2 was used as base to define the causal relationships and the feedback loops that define the reinforcing and balancing forces within the innovation system.

Reinforcing loops are circular causation mechanisms that link two or more variables and that produce a reinforcing behavior distributed among its variables. Balancing loops on the other hand, define circular causation mechanisms that link two or more variables producing a reducing effect among its variables. The interactions between different loops define in turn, dominant ones that drive the behavior of the system. The causal loop model has proven that an innovation system is basically structured of circular causation mechanisms related with the means of learning and knowledge accumulation, and that they drive the behavior of the system, by encouraging the dominance of some learning loops instead of others.

Thus, it can be concluded that feedback mechanisms, learning loops and knowledge accumulation are the drivers of innovation systems and that they provide useful insights to understand the complex dynamic behavior of innovation systems.

5.4 Concluding Remarks

This chapter has presented the modeling framework, by using two methods: a systematic review of the literature and causal loop diagrams from system dynamics.

The systematic review served to synthesize a large amount of previous models into a single modeling framework, composed of a Financing and Funding component, a Science and Technology component, a Technological Production component, a Consumer Market component and a Human Capital component. Although it may be argued that the variety of models and modeling approaches are specific to each study and that in fact their diversity enriches the innovation systems literature, models are subject to bias, lack of knowledge and subjectivity. Thus, by using a logic and coherent framework composed of a group of essential components and linkages to design models, the subjectivity and bias problems would be dramatically reduced since, there would be a logic to define what is actually contained in the model: the boundaries, the linkages and the components, and which actually may prove even more valuable than the current vast diversity of models out there.

In addition, the framework identifies that different types of learning activities affect different elements on the innovation system and that STI knowledge and DUI knowledge are the main knowledge accumulation mechanisms.

In synthesis, the framework describes in detail how knowledge and learning processes are linked to each other and how they affect the innovation system from a descriptive yet static perspective.

Second, the modeling framework was used to build a causal loop model. The causal loop model has proven that an innovation system is basically structured of circular causation mechanisms that are structured by means of learning processes and knowledge accumulation.

6

System Dynamics Model Design and Simulation Experiments

This Chapter instantiates the modeling framework for the case of the Software Sector, by using a sectoral innovation systems approach, presents the formalization of the system dynamics model and concludes with the several simulation experiments aimed at testing the dynamic behavior of the system in study.

Thus, the chapter begins by presenting the data from PINTEC editions 2005 and 2008 for the Software Sector in Brazil and other additional sources of information, which are shown in an extended version in Appendix 2. In the second Section, the chapter describes the stock and flow model, i.e. simulation model, based on modeling framework of Section 5.2, on the CLD model from Section 5.3 and on data from PINTEC survey from the Software Sector in Brazil. In the third Section, the chapter shows the results of the model validity tests for system dynamics. The fourth Section presents four simulation experiments, based on the concepts of technological regimes. The chapter ends up with the main concluding remarks.

In addition, each Section of the chapter ends up with a short synthesis describing its main findings and conclusions and highlighting their attendance to the research objectives of this dissertation.

6.1 Model instantiation: the case of the Software Sector in Brazil

In recent decades, there has been an increasing interest on the so-called Knowledge Intensive Business Services (KIBS) and their role as servers of other high-tech and low-tech industries. KIBS produce intangibles, which are knowledge-intensive in nature and which require high levels of qualified staff and usually low levels of capital goods (Miles et al., 1995; Miles, 2005; Muller and Doloreux, 2009). Within the KIBS sectors, the Software Sector is one of the most innovative and dynamic industries in developed economies and in some catching-up economies as well (DTI, 2003; Tether and Swan, 2003; Niosi et al., 2012).

Software products and related services are complex in nature. They rely on expert knowledge and on a specialized knowledge base to be developed (Malerba and Nelson, 2011), they also rely on highly creative stages - conceptualization, requirements analysis and high-level design and specialized related services - consulting, training and software set-up, operation and maintenance. Such broad field of expertise and applications, often make statistical measurements difficult, in the sense that identifying all of these variables with limited time and other resources is a challenging task.

Second, software is of intangible nature. There is packaged software, custom software, software-as-a-service, embedded software, cloud computing and so on, which brings the problem of variability in the treatment of software statistics. This means that different countries may treat different groups of software activities in their national statistics which may not necessarily be of equal representation in another country, making the comparability issue a delicate and caution-like one (Lippoldt and Stryszowski, 2009). Another issue to take into account is that literature proves that often software firms use non-traditional approaches to development, production and distribution of their products (Lippoldt and Stryszowski, 2009), leading us to a third point: lack of data for non-traditional approaches and for in-house software not meant for commercial distribution outside the firm. In this sense, international comparability of non-traditional approaches might be flawed and also the accounting treatment of software investments.

All of the issues above, produce several constrains from a methodological perspective, that difficult a more standardized measurement of software activities, arising a lack of internal knowledge about the software sector within nations and regions, and also a lack of comparability indicators with other countries and regions, due to the lack of standardized measurements.

Thus, it can be argued that current data and related statistics on the software sector are either aggregated within broader sectors, such as the Information and Communication Technologies (ICT) Sector; within similar sectors, such as Software and related IT services Sector; and within supplemental sectors, such as Computers and related services Sector. Although data on related and similar broader sectors could not be used to assess the state of the software sector in particular, at least, it could offer insights about how broader sectors are doing (in which software sector is part of), and therefore, they could be used to make general inferences on the software sector as well. Appendix 2 presents an extended overview of the software sector in Brazil, based on PINTEC data and other additional sources, which served as the base for the following Sections.

In particular, this Dissertation used data from the PINTEC survey to instantiate the stock and flow model building process. Specifically, data from two sub-categories: "Software consulting" and "Other information technology and services related activities", with a total sample of 3811 firms, from the PINTEC-2005 edition (IBGE, 2007); and two sub-categories: "Development and licensing of computer programs" and "Other information technology services" with a total sample of 2514 firms, from the PINTEC-2008 edition (IBGE, 2010) were used as proxies for the Software Sector in Brazil.

6.1.1 Data collected from PINTEC-2005 and PINTEC-2008

Expenditures in innovative activities

PINTEC includes data from eight types of innovative activities and specifically from the total expenditures on each type of innovative activity done by firms for years 2005 and 2008.

Expenditures on in-house R&D include both direct and indirect expenses on R&D activities, such as R&D labor costs, services, software and equipment for R&D. External R&D expenditures include all external expenditures for R&D activities performed by an external organization. Expenditures with the acquisition of external knowledge include technology transfer agreements from patent and license acquisitions, copyrights, know how, etc. Expenditures with software include all expenses related with the acquisition of software products for product and process innovation. Training expenditures include all training activities related with product and process development. Expenditures with the introduction of technological innovation into the market includes all expenses related with marketing, market research, advertising, etc. Expenditures with industrial design and other technical setups includes all other types of expenses not mentioned in the above categories, such as blueprints, technical specifications, etc.

Thus, Figure 6.1 presents the expenditures on innovative activities, classified by type of innovative activity, based on PINTEC data.

Innovative activity expenditures in the Software Sector	Code	2005 (1 USD = 2.3607 BRL)*		2008 (1 USD = 2.33BRL)*	
		(x1000USD)	(%)	(x1000USD)	(%)
In-House R&D	IRD	262 736	39.3%	125 763	30.4%
External R&D	ERD	15 702	2.4%	9 782	2.4%
Acquisition of external knowledge	EEK	48 209	7.2%	25 385	6.1%
Acquisition of machinery and equipment	EME	143 098	21.4%	157 452	38.1%
Acquisition of software	ESO	47 724	7.1%	23 295	5.6%
Training	EWT	78 011	11.7%	19 435	4.7%
Introduction of technological innovations into the market	EWC	53 314	8.0%	22 749	5.5%
Industrial design and other technical setups	EOP	19 319	2.9%	29 891	7.2%
Total Innovation Expenditures		**668 112**	**100.0%**	**413 752**	**100.0%**

(*) Data from Banco Central do Brasil

Figure 6.1: **Expenditures on innovative activities in the Software Sector sample of firms** - Source: Adapted from PINTEC-2005 and 2008

As shown in Figure 6.1, in-house R&D and the acquisition of machinery and equipment were the two categories with the largest shares in 2005 and 2008. However, data on Figure 6.1 accounts only for the total sampled firms of 2005 and 2008, therefore, the values of the whole software sector may be inferred by calculating the average expenditure per innovative activity per firm in the sample and then multiplying the average expenditure per innovative activity per firm with the total number of firms for 2005 and 2008, formalized in the following equations:

$$\text{aEIA}_i = \frac{IA_i}{F_j} \quad (6.1)$$

where:
$aEIA =$ Average expenditure on innovative activity
$IA =$ Innovative Activity
$F =$ Number of firms on sample
$i =$ each type of innovative activity
$j =$ year (2005,2008)

Figure 6.2 shows the converted values for the whole sector, based on the calculations previously mentioned.

Innovative activity expenditures in the Software Sector (total firms)	Code	2005 Firms =	7760	2008 (*)Firms =	8133
		(x1000USD)	(%)	(x1000USD)	(%)
In-House R&D	IRD	1 114 723	39.3%	821 553	30.4%
External R&D	ERD	66 620	2.4%	63 902	2.4%
Acquisition of external knowledge	EEK	204 540	7.2%	165 825	6.1%
Acquisition of machinery and equipment	EME	607 129	21.4%	1 028 559	38.1%
Acquisition of software	ESO	202 480	7.1%	152 174	5.6%
Training	EWT	330 982	11.7%	126 962	4.7%
Introduction of technological innovations into the market	EWC	226 196	8.0%	148 611	5.5%
Industrial design and other technical setups	EOP	81 964	2.9%	195 262	7.2%
Total Innovation Expenditures		**2 834 635**	**100.0%**	**2 702 848**	**100.0%**

(*) estimated value based on historical data

Figure 6.2: **Expenditures on innovative activities in the Software Sector total firms** - Source: Adapted from PINTEC-2005 and 2008

At the same time, as shown in Figure 6.3, in 2005, 95% of funding for innovative activities was from firm's own resources for both R&D and the rest of activities. In 2008 it remained the largest although at a diminishing share, with 63% funding on R&D activities and 82% on other activities. On the other hand, third-party funding accounted for only 5% of total expenditures in 2005 and 37% on R&D expenditures in 2008 and 18% on other activities in the same year.

Funding Sources share - R&D and other activities (Software Sector)	Code	Software Sector (2005)		Software Sector (2008)	
		R&D	Others	R&D	Others
Own Funding (a)	POF	95.0%	95%	63.0%	82%
Third-party funding - private (c)	IPR	4%	3%	3%	15%
Third-party funding - public (d)	IPU	1%	2%	34%	3%
Total (a+b)		**100.0%**	**100.0%**	**100.0%**	**100.0%**

Figure 6.3: **Funding sources of innovative activities in the Software Sector sample of firms** - Source: Adapted from PINTEC-2005 and 2008

Data on funding may need to be converted to absolute values, by using the percentage shares shown in Figure 6.3 and the actual total expenditures on innovative activities of Figure 6.2. Thus, it is assumed that the total expenditures on innovative activities for both years equaled the total funding on the same years, meaning that, for instance, own funding from firms reinvestments in 2005 represented $95\% * 2.69Bi[USD]$. Such calculations are performed, based on Eq. (6.2), (6.3), and (6.4):

$$POF(t) = [\frac{\alpha}{IRPOF_{\alpha}}] + [\frac{\beta}{IRPOF_{\beta}}] \tag{6.2}$$

$$IPR(t) = [\frac{\alpha}{IRIPR_{\alpha}}] + [\frac{\beta}{IRIPR_{\beta}}] \tag{6.3}$$

$$IPU(t) = [\frac{\alpha}{IRIPU_{\alpha}}] + [\frac{\beta}{IRIPU_{\beta}}] \tag{6.4}$$

Where:
POF = Privately-owned Funding
IPR = Investments from Private Sector
IPU = Investments from Public Sector
α = IRD(t) + ERD(t)
β = EEK(t)+EME(t)+ESO(t)+EWT(t)+EWC(t)+EOP(t)
$IRPOF_{\alpha}$ = Investment Rate POF of α activities
$IRPOF_{\beta}$ = Investment Rate POF of β activities
$IRIPR_{\alpha}$ = Investment Rate POF of α activities
$IRIPR_{\beta}$ = Investment Rate POF of β activities
$IRIPU_{\alpha}$ = Investment Rate POF of α activities
$IRIPU_{\beta}$ = Investment Rate POF of β activities

Using equations Eq. (6.2), (6.3), and (6.4) we can derive the results shown in Figure 6.4.

Funding Sources share - R&D and other activities (Software Sector)	Code	Software Sector (2005)			Software Sector (2008)		
		R&D	non-R&D	TOTAL	R&D	non-R&D	TOTAL
Own Funding (a)	POF	1 122 276	1 570 628	2 692 904	557 837	1 490 262	2 048 099
Third-party funding - public (b)	IPU	47 254	49 599	96 852	26 564	272 609	299 173
Third-party funding - private (c)	IPR	11 813	33 066	44 879	301 055	54 522	355 577
Total (a+b+c)		**1 181 343**	**1 653 292**	**2 834 635**	**885 455**	**1 817 393**	**2 702 848**

Values in x1000 USD

Figure 6.4: **Funding sources of innovative activities in the Software Sector** - Source: Adapted from PINTEC-2005 and 2008

According to Figure 6.4, total innovative activities for the software sector accounted for 2.83 Bi [USD] in 2005 and for 2.70 Bi [USD] for 2008.

Personnel employed in the Software Sector

PINTEC data on the size of R&D personnel in the Software Sector was also collected as Figure 6.5 shows.

Personnel engaged in in-house R&D	2005	2008
Firms (Total) (a)	3 811	2 514
Firms with expenditures in-house R&D (b)	1 015	328
Personnel employed (Total) (c)	224 658	201 185
Total Personnel employed (in-house R&D) (d=e+f+g)	12 095	3 367
Personnel with Advanced degree (e)	1 100	335
Personnel with Undergraduate degree (f)	8 306	2 344
Personnel with Technical degree (g)	2 689	688
Average R&D personnel per firm - (d/b)	**11.9**	**10.3**
Share of Personnel with advanced degree (e/d)	**9.1%**	**9.9%**
Share of Personnel with undergrad degree (f/d)	**68.7%**	**69.6%**
Share of Personnel with technical degree (g/d)	**22.2%**	**20.4%**
Total	**100.0%**	**100.0%**

Figure 6.5: **Personnel employed in the Software Sector Total and R&D sample of firms** - Source: Adapted from PINTEC-2005 and 2008

Since only a group of firms engage on in-house R&D, the average R&D personnel per firm is calculated by using the following equation:

$$ARD = \frac{(PAD + PUD + POD)}{FRD} \qquad (6.5)$$

Where:
ARD = Average R&D per firm
PAD = Personnel with advanced degree PUD = Personnel with undergraduate degree
POD = Personnel with other degree
FRD = Firms with expenditures on in-house R&D

Importance of Information Sources for the innovative process

Information flows from different sources were also gathered out from PINTEC surveys. Specifically, data related with the relative importance of each information source for the innovative process in the Software Sector.

In this sense, firms in both PINTEC surveys checked the importance of each information source by using a scale (High Importance, Medium

Importance and Low Importance). We used a weighted average for each item in order to gather as much qualitative insights as possible. Thus, we used Eq. (6.6). Later, the weighted averages were normalized (0-1 scale), in order to be used in the model, following Eq. (6.7).

$$\omega_i(t) = \frac{[(2 * High_i(t)) + (1 * Medium_i(t)) + (0 * Low_i(t))]}{3} \quad (6.6)$$

$$\rho_i(t) = \frac{\omega_i(t)}{(High_i(t) + Medium_i(t) + Low_i(t))} \quad (6.7)$$

Where:
$\omega = Weightedaverageof$i
$\rho = Relativevalueof$i
i$= eachinformationsource$
High$_i$ = total number of firms who answered information source i was of high importance
$Medium_i$ = total number of firms whom answered that information source i was of medium importance.
Low_i = total number of firms whom answered that information source i was of low importance.

The results of such computation calculus are summarized in Figure 6.6.

Information Sources - Relative Importance	2005	2008
Inf. Flows from R&D Department	0.41	0.52
Inf. Flows from other knowledge	0.35	0.41
Inf. Flows from suppliers	0.31	0.24
Inf. Flows from customers	0.39	0.45
Inf. Flows w/competitors	0.27	0.26
Inf. Flows from consulting, etc.	0.14	0.23
Inf. Flows from Universities	0.10	0.15
Inf. Flows from Research Institutes	-	0.10
Inf. Flows from training	0.08	0.10
Inf. Flows from Testing Centers	0.06	0.12
Inf. Flows from patents, etc.	0.29	-
Inf. Flows from Conferences, Publications, etc	0.19	0.26
Inf. Flows from fairs and expositions	0.19	0.20
Inf. Flows from Informatized Networks (Internet)	0.42	0.56

Figure 6.6: **Importance of information sources by type of innovative activities** - Source: Adapted from PINTEC-2005 and 2008

As Figure 6.6 shows, all values have increased but the relative importance of suppliers as information sources. Information flows from competitors have remained approximately constant, as well as information flows from fairs and expositions.

Importance of innovative activities for the innovation process

Data of the importance of innovative activities was also retrieved from PINTEC-2005 and PINTEC-2008. In order to normalize the data on the range of 0-1, equations similar to Eq. (6.6) and Eq. (6.7) of Section above were used. The summary of the normalization exercise are found in Figure 6.7.

Innovative activities - relative importance	2005	2008
Importance of in-house R&D	0.29	0.16
Importance of external R&D	0.02	0.03
Importance of other knowledge - Acquisition of external knowledge	0.15	0.13
Importance of suppliers - Equip and Software	0.35	0.33
Importane of training	0.38	0.37
Importance of tech innov for the market	0.14	0.29
Importance of other technical prep.	0.12	0.21

Figure 6.7: **Importance of innovative activities in the software sector sample of firms** - Source: Adapted from PINTEC-2005 and 2008

The category "importance of suppliers" is composed by the acquisition of machinery and equipment and by the acquisition of software. Since machinery and equipment for the Software Sector are basically hardware and computer equipment (in general), the category "importance of suppliers" could be simplified by composing both sub-categories into a single one (containing both hardware and software acquisition). Therefore, the following equation was used to create the composite category:

$$ISU(t) = \frac{IMM + ISO}{2} \qquad (6.8)$$

Where:

ISU = Importance of suppliers

IMM = Importance of the acquisition of machinery and equipment

ISO = Importance of the acquisition of software

6.1.2 Summary of the data collected from the Software Sector

The summary of the data extracted from PINTEC-2005 and PINTEC-2008 to be used in the instantiation of the model for the Software Sector in Brazil is presented in Figure 6.7 and organized by component of the modeling framework to which they belong.

Component	Variable	Acronym	Value - 2005	Value - 2008	Units
Financing and Funding	Expenditure with in-house R&D	IRD	1 114 723	821 553	x1000USD
	Expenditure with external R&D	ERD	66 620	63 902	x1000USD
	Expenditure with external knowledge	EEK	204 540	165 825	x1000USD
	Expenditure with software	ESO	202 480	152 174	x1000USD
	Expenditure with Machinery and Equip.	EME	607 129	1 028 559	x1000USD
	Expenditure with other tech prep	EOP	81 964	195 262	x1000USD
	Expenditure with commercialization	EWC	226 196	148 611	x1000USD
	Expenditures with training	EWT	330 982	126 962	x1000USD
	Privately-owned funding	POF	2 692 904	2 048 099	x1000USD
	Public investments	IPU	96 852	299 173	x1000USD
	Private investments	IPR	44 879	355 577	x1000USD
Science and Technology	Importance of in-house R&D	IIR	0.29	0.16	Dimensionless
	Importance of external R&D	IER	0.02	0.03	Dimensionless
	Inf Flows from R&D Dept.	FIR	0.41	0.52	Dimensionless
	Inf. Flows from Universities	FUR	0.10	0.15	Dimensionless
	Inf. Flows from Testing Centers	FTR	0.06	0.12	Dimensionless
Technological Production	Inf. Flows from other knowledge	FOP	0.35	0.41	Dimensionless
	Inf. Flows from customers	FWC	0.39	0.45	Dimensionless
	Inf. Flows from consulting, etc.	FWO	0.14	0.23	Dimensionless
	Inf. Flows from Conferences, Publications, etc	ICP	0.19	0.26	Dimensionless
	Inf. Flows from fairs and expositions	IFE	0.19	0.20	Dimensionless
	Inf. Flows from Informatized Networks (Internet)	ITT	0.42	0.56	Dimensionless
	Inf. Flows from suppliers	FSU	0.31	0.24	Dimensionless
	Inf. Flows from training	FWT	0.08	0.10	Dimensionless
	Inf. Flows w/competitors	FCM	0.27	0.26	Dimensionless
	Inf. Flows from patents, etc.	FPM	0.29	-	Dimensionless
	Importance of other technical prep.	IOP	0.12	0.21	Dimensionless
	Importance of tech innov for the market	IWC	0.14	0.29	Dimensionless
	Importance of suppliers	ISU	0.35	0.33	Dimensionless
	Importance of other knowledge	IOK	0.15	0.13	Dimensionless
	Importane of training	IWT	0.38	0.37	Dimensionless
Consumer Market	Sector Attractiveness	SAT	0.5	0.5	Dimensionless
	Product Attractiveness	PAT	0.5	0.5	Dimensionless
Human Capital	Personnel w/technical degree in R&D	POD	2 689	688	people/year
	Personnel w/undergrad degree in R&D	PUD	8 306	2 344	people/year
	Personnel w/ advanced degree in R&D	PAD	1 100	335	people/year
	Average R&D personnel per firm	ARD	12	10	people/year/firm

Figure 6.8: **Summary of data extracted from PINTEC** - Source: Adapted from PINTEC-2005 and 2008

6.1.3 Synthesis

This Section has described the main data from PINTEC, used to instantiate the model for the software sectoral innovation system. It has shown that due to the lack of standardized time series datasets, the analysis of software activities is a challenging task and therefore, no current data source may be completely adequate use in sectoral studies for the software sector.

Since there is no current datasets that group at least a moderate number of indicators in the form of time series for a relatively long period of time, this Dissertation opted out in using data from the PINTEC surveys, which represent the largest and broadest dataset on innovative activities in Brazil by sampling a large number of firms, which is its major advantage. In this sense, data from the last two editions, PINTEC-2005 and PINTEC-2008 were analyzed and specific categories were selected.

The first category, expenditures in innovative activities and funding sources, data from PINTEC was used to estimate overall sector amounts, since PINTEC obviously offered data relative only to the firms it sampled. In the next category, personnel employed in the software sector, the average personnel per firm had to be calculated, so it could be used in the model. Finally, importance of information sources for the innovative process and importance of innovative activities were normalized in the range (0-1) for each one of their categories.

The major shortcoming of PINTEC is that it does not offer data enough to build time series and therefore to estimate parameters and behaviors in a more accurate way, since only the two last editions accounted for software activities. Still, data collection proved to be adequate for the purposes of this Dissertation, and additional data sources and calculations are left for future studies.

6.2 Stock and Flow Model Design

Although Causal Loop Diagrams are helpful in identifying and offering explanations for observed behavior in the real system, they need to be tested out and formalized in simulation models, which are known as stock and flow diagrams. The stock and flow model is based on the structure proposed in the modeling framework previously discussed: Financing and Funding, Science and Technology, Technological Production, Consumer Market and Human Capital. In addition, the simulation model links the components discussed above by using the causal relationships identified in the CLDs, using both, reinforcing and balancing loops. The complete simulation model is presented in Figure 6.9.

As shown on Figure 54, the simulation model is composed by twelve stocks or state level variables, interlinked among them by following the causal loops described in Section 5.3. Due to the complexity of the model, each component will be described in detail, at the equation level in the following Sections.

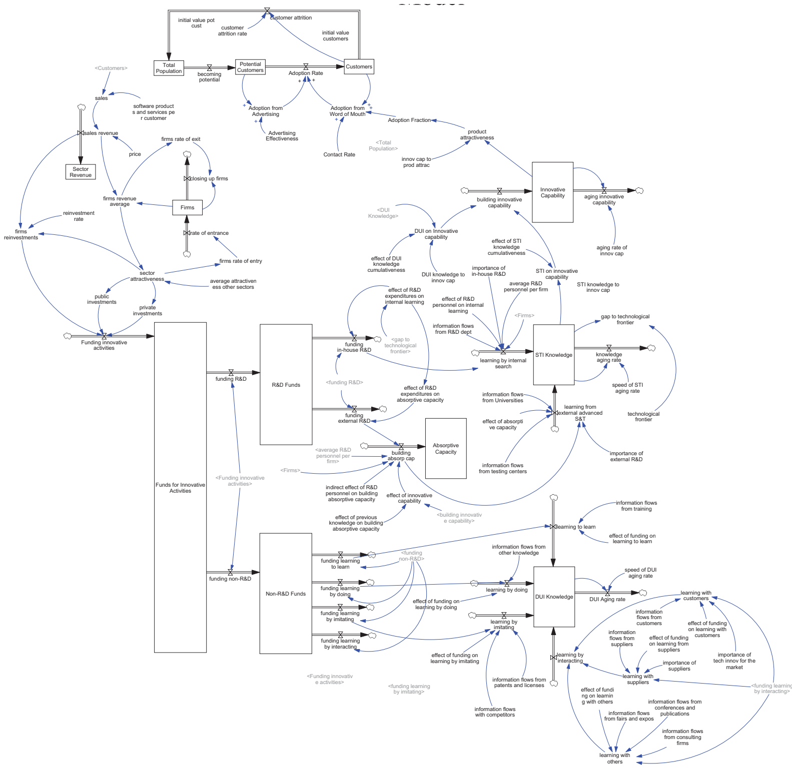

Figure 6.9: **Complete simulation model for the software sectoral innovation system in Brazil** - Source: Author

6.2.1 Financing and Funding Submodel

The submodel for the Financing and Funding component relates market results (represented by firms revenue average) with the sector attractiveness variable, which defines the investment levels for firms, private sector and public sector. The decision of investment for the three actors is based on the comparison between the firms revenue average and the average attractiveness other sectors (Figure 6.10.

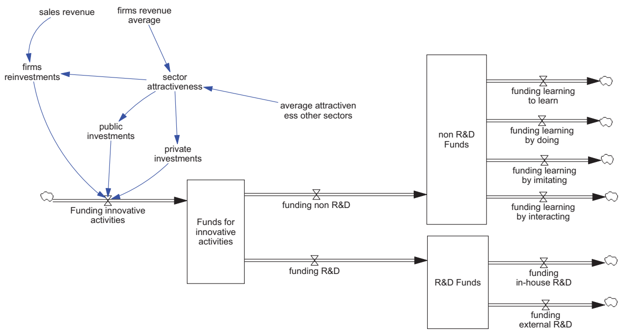

Figure 6.10: **Financing and Funding simulation model** - Source: Author

Thus, sector attractiveness is defined by the following equation:

$$SAT = \frac{FRA}{ATO} \tag{6.9}$$

Where:
SAT = Sector Attractiveness
FRA = Firms average revenue
ATO = Average attractiveness of other sectors

The equilibrium point is when both values are the same, conferring sector attractiveness the value of 1 (scale from 0 to 1). Sector attractiveness is linked with firms reinvestments, public investments and private investments by using a nonlinear function, which represents the resource allocation decision, determined and modeled as an $S - shaped$ curve, as suggested by Tayaran (2011) in the following equations:

$$\frac{d}{dt}IDFI = \frac{1}{1 + e^{-g_1 * SAT(t)}} \tag{6.10}$$

$$\frac{d}{dt}IDPR = \frac{1}{1 + e^{-g_2 * SAT(t)}} \tag{6.11}$$

$$\frac{d}{dt}IDPU = \frac{1}{1 + e^{-g_3 * SAT(t)}} \tag{6.12}$$

Where:
IDFI = Investment decision of firms
IDPR = Investment decision of private sector
IDPU = Investment decision of public sector
g_i = constant-specific to each industry

On the other hand, funding innovative activities is feed up by firms reinvestments, private investments and public investments, as seen on Eq. (6.13). The state level Funds for Innovative Activities is formalized in Eq. (6.14).

$$\frac{d}{dt}FIA(t) = f(FI, PR, PU) \tag{6.13}$$

$$FUN(t) = \int_{t_0}^{t} \frac{d}{dt}FIA(t) - \frac{d}{dt}FNR\frac{d}{dt}FRD \tag{6.14}$$

Where:
FIA = Funding innovative activities
FUN = Funds for innovative activities
FNR = Funding non-R&D
FRD = Funding R&D

Accordingly, funding non-R&D and funding R&D rates were parameterized, based on data from PINTEC-2005 and PINTEC-2008.

The second state variable in this component, non-R&D Funds follows a similar structure to Eq.(6.15):

$$NRDF(t) = \int_{t_0}^{t} \frac{d}{dt}[FNR(t) - FLTL(t) - FLBD(t)FLBI(t) - FLBN(t)] \tag{6.15}$$

Where:
NRDF = Non-R&D Funds
FLTL = Funding learning to learn
FLBD = Funding learning by doing
FLBI = Funding learning by imitating

FLBN = Funding learning by interacting

The dependent variables of the former equation follow different equation structures, which will be described in later Sections.

Similarly, the third state variable, R&D Funds is modeled through the following equation:

$$RDF(t) = \int_{t_0}^{t} \frac{d}{dt}[FRD(t)IRD(t)ERD(t))] \tag{6.16}$$

Where:
RDF = R&D Funds
FRD = Funding R&D
IRD = Funding in-house R&D
ERD = Funding external R&D

6.2.2 Science and Technology Submodel

This submodel represents the relationships between three stock variables: R&D Funds, Absorptive Capacity and STI Knowledge (Figure 6.11). Equations for each one of them will be introduced in the following paragraphs.

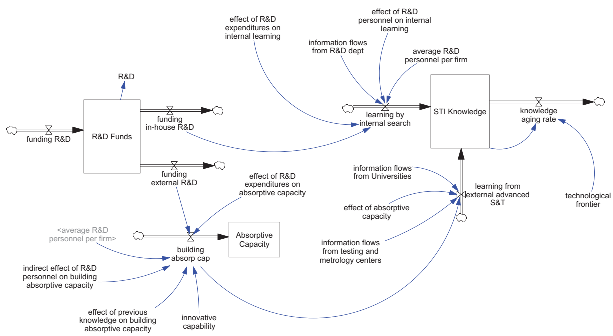

Figure 6.11: **Science and Technology simulation model** - Source: Author

R&D Funds is modeled through Eq. (6.16), as described before. In parallel, funding in-house R&D and funding external R&D are modeled by using a set of parameters obtained in PINTEC-2005 and PINTEC-2008.

The absorptive capacity of firms in the software sector is built through the following equations.

$$AC(t) = \int_{t_0}^{t} \frac{d}{dt} bAC(t) \tag{6.17}$$

Where:
AC (t) = Absorptive Capacity
bAC (t) = Building Absorptive Capacity

$$\frac{d}{dt} bAC = f(ERD, RDAC, IC, EKbAC, iEPbAC, ARD) \tag{6.18}$$

Where:
ERD = funding external R&D
RDAC = effect of R&D expenditures on absorptive capacity
IC = innovative capability
EKbAC = effect of previous knowledge on building absorptive capacity
iEPbAC = indirect effect of R&D personnel on building absorptive capacity
ARD = average R&D personnel per firm

Funding in-house R&D in turn, influences on learning by internal search, along with the following parameters: effect of R&D expenditures on internal learning, effect of R&D personnel on internal learning and average R&D personnel per firm. Funding in-house R&D is related to the effect of R&D expenditures on internal learning. Similarly, the average R&D personnel per firm variable was modeled as a fraction of the effect of R&D personnel on internal search as shown.

$$E = \frac{IRD}{RDIL} \tag{6.19}$$

$$P = \frac{ARD}{EPIS} \tag{6.20}$$

Where:
IRD = funding in-house R&D
RDIL = effect of R&D expenditures on internal learning
EPIS = effect of R&D personnel on internal search

Learning by internal search accounts for both types, R&D expenditures and R&D personnel equally, therefore it is modeled as an S-shape equation where the average value of both effects is taken into account:

$$\frac{d}{dt}LIS = f(IRD, FIR, ARD) \tag{6.21}$$

Where:
LIS = Learning by internal search
FIR = Information Flows from R&D Department

Learning from external advanced S&T is related with a nonlinear equation to absorptive capacity:

$$\frac{d}{dt}LES = f(bAC, FUR, FTR, EAC) \tag{6.22}$$

Where:
LES = Learning from external advanced S&T
FUR = Information flows from universities
FTR = Information flows from testing and metrology centers
EAC = Effect of Absorptive Capabity

The other flow related with STI knowledge is knowledge aging rate, which is modeled using the equation proposed by Garcia et al. (2003).

$$\frac{d}{dt}KAR_{STI} = f(TF, K_{STI}, t_k) \tag{6.23}$$

Where:
KAR_STI = STI Knowledge aging rate
TF = Technological Frontier
K_{STI} = STI Knowledge
t_k = length of time in months in which knowledge becomes outdated

All three flows link with the state variable STI knowledge as modeled by the equation:

$$K_{STI}(t) = \int_{t_0}^{t} \frac{d}{dt}LIS + \frac{d}{dt}LES - \frac{d}{dt}KAR_{STI} \tag{6.24}$$

6.2.3 Technological Production Submodel

The Technological Production submodel is similar to the science and technology component. The first state variable Non-R&D Funds was previously modeled through Eq.7. The rates, funding non-R&D, funding learning to learn, funding learning by doing, funding learning by imitating and funding learning by interacting were parametrized by using data from PINTEC-2005 and PINTEC-2008, as shown in Figure 6.12.

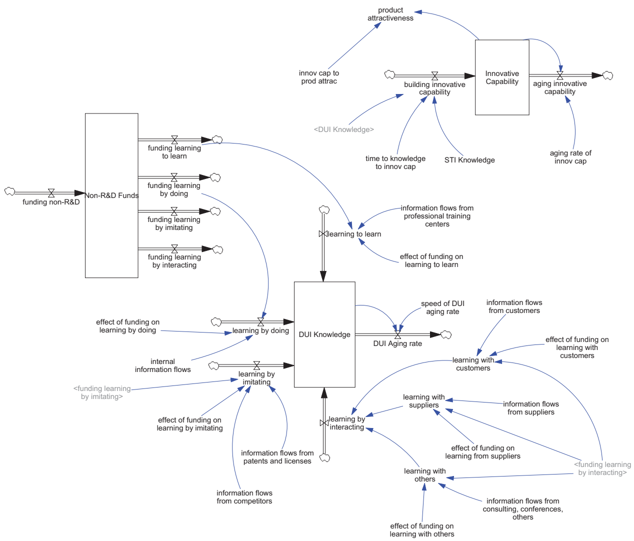

Figure 6.12: **Technological Production simulation model** - Source: Author

The second state variable in this component, DUI knowledge is composed of four learning types and one outflow which represents the aging process of knowledge, modeled as shown next:

$$K_{DUI}(t) = \int_{t_0}^{t} LTL + LBD + LBI + LBN - KAR_{DUI} \qquad (6.25)$$

Where:
K_{DUI} = DUI Knowledge
LTL = Learning to learn
LBD = Learning by doing
LBI = Learning by imitating
LBN = Learning by interacting
KAR_{DUI} = DUI Knowledge aging rate

Learning to learn is modeled as a function of funding learning to learn, information flows from professional training centers and effect of funding on learning to learn, as formalized in:

$$\frac{d}{dt}LTL = f(FLTL, FWT, EFLTL) \tag{6.26}$$

Where:
FLTL = Funding learning to learn FWT = Information flows from professional training centers
EFLTL = Effect of funding on learning to learn

Similarly, learning by doing is formalized as:

$$\frac{d}{dt}LBD = f(FLBD, FOP, EFLBD) \tag{6.27}$$

Where:
FLBD = Funding learning by doing
FOP = Information flows from other internal departments
EFLBD = Effect of funding on learning by doing

The equation for learning by imitating is shown in Eq.(6.28) and the equation for learning by interacting in Eq.(6.29), as shown below:

$$\frac{d}{dt}LBI = f(FLBI, FCM, FPM, EFLBI) \tag{6.28}$$

$$\frac{d}{dt}LBN = f(LWC, LWS, LWO) \tag{6.29}$$

Where:
LBI = Learning by imitating
FLBI = Funding learning by imitating
FCM = Information flows from competitors
FPM = Information flows from patents, licences
EFLBI = Effect of funding on learning by imitating
LBN = Learning by interacting
LWC = Learning with customers
LWS = Learning by suppliers
LWO = Learning with others

On the other hand, the three learning subtypes from Eq.(6.29) were modeled as follow:

$$\frac{d}{dt}LWC = f(FLBN, FWC, EFLWC) \tag{6.30}$$

$$\frac{d}{dt}LWS = f(FLBN, FSU, EFLWS) \tag{6.31}$$

$$\frac{d}{dt}LWO = f(FLBN, FWO, ICP, EFLWO) \tag{6.32}$$

Where:

FLBN = Funding learning by interacting
FWC = Information flows from customers
EFLWC = Effect of funding on learning with customers
FSU = Information flows from suppliers
EFLWS = Effect of funding on learning with suppliers
FWO = Information flows from consulting
ICP = Information flows from conferences
EFLWO = Effect of funding on learning with others

The third state variable in this component is innovative capability, which is build up through flows of STI knowledge and DUI knowledge, as shown next.

$$\frac{d}{dt}bIC = f(K_{DUI}, K_{STI}, Time_K) \tag{6.33}$$

Where:
bIC = Building Innovative Capability
$Time_K$ = Lenght of time needed for STI and DUI to become actual drivers of innovative capability.

The outflow aging innovative capability is similar to previous aging equations and is formalized as:

$$\frac{d}{dt}aIC = f(AR_{IC}, IC) \tag{6.34}$$

Where:
aIC = Aging Innovative Capability
AR_{IC} = Aging rate of innovative capability, and is an industry-specific constant
IC = Innovative Capability

Thus, the state variable Innovative Capability is defined by the following equation:

$$IC(t) = \int_{t_0}^{t} bIC - aIC \tag{6.35}$$

Where:
bIC = Building Innovative Capability
aIC = Aging Innovative Capability

Finally, the variable product attractiveness is a nonlinear function of the form:

$$PAT = \frac{IC}{IC_{PAT}} \tag{6.36}$$

Where:
PAT = Product Attractiveness
IC_{PAT} = Lenght of time for innovative capability to affect product attractiveness

6.2.4 Consumer Market Submodel

The Consumer Market submodel is composed by six state variables as shown in Figure 6.13. The first three represent an aging chain (Sterman, 2000), in which a population becomes aware of the new product, becoming potential customers and later actual customers. The equations that formalize the aging chain are the following:

$$TP(t) = \int_{t_0}^{t} CAT - BPO \tag{6.37}$$

$$PC(t) = \int_{t_0}^{t} BPO - ART \tag{6.38}$$

$$CUS(t) = \int_{t_0}^{t} ART - CAT \tag{6.39}$$

Where:
TP = Total Population of customers
CAT = Customer attrition rate
BPO = Becoming potential customers
ART = Customer Adoption Rate

Moreover, CAT is a rate variable that represents the amount of customers that are lost and that return as part of the total population. It depends on a customer attrition rate and on the total amount of customers:

$$\frac{d}{dt}CAT = f(CAT, CUS) \tag{6.40}$$

The becoming potential BPO variable is represented as a constant rate so it does no influence on the overall behavior of the model.

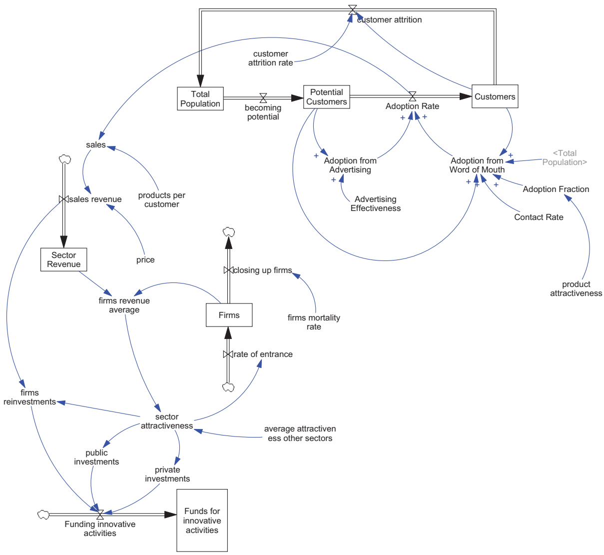

Figure 6.13: **Consumer Market simulation model** - Source: Author

Adoption rate depends on two adoption variables: adoption from advertising and adoption from word of mouth. Adoption from advertising in turn, depend on the advertising effectiveness which is a value taken from PINTEC and from the number of potential customers. Adoption from word of mouth depends on a constant parameter (contact rate), on the adoption fraction, which depends itself on the product attractiveness, on the total population and on the potential customers and actual customers, as shown in the following equations:

$$\frac{d}{dt}ART = f(ADV, AWM) \tag{6.41}$$

$$\frac{d}{dt}ADV = f(POT, ADE) \tag{6.42}$$

$$\frac{d}{dt}AWM = f(CR, AF, TP, POT, CUS) \tag{6.43}$$

$$\frac{d}{dt}AF = f(PAT) \tag{6.44}$$

Where:
ADV = Adoption from advertising
AWM = Adoption from word of mouth
POT = Potential customers
ADE = Advertising Effectivness
CR = Contact Rate
AF = Adoption Fraction
TP = Total Population
CUS = Customers
PAT = Product Attractiveness

Advertising effectiveness is a parameter on the range between 0 and 1, similar to contact rate, product attractiveness and adoption fraction.

Sales are defined as a function of customers and software products per customer as shown in the following Equation:

$$\frac{d}{dt}SAL = \frac{d}{dt}CUS * \frac{d}{dt}PCU \tag{6.45}$$

Where:
SAL = Sales
CUS = Customers
PCU = Products per customer

sales revenue then, are the result of:

$$SRV(t) = SAL(t) * PRC(t) \tag{6.46}$$

Where:
SRV = Sales revenue
SAL = Sales
PRC = Price

Firms are modeled as the result of two flow rates as shown next:

$$Firms(t) = ROE(t) - CUF(t) \tag{6.47}$$

$$\frac{d}{dt}ROE = SAT(t) * FRE * Firms \tag{6.48}$$

$$\frac{d}{dt}CUF = FRX * Firms \tag{6.49}$$

Where:
ROE = Firms Rate of Entrance
CUF = Closing up firms
SAT = Sector Attractiveness
FRE = Firms rate of entry
FRX = Firms rate of exit

On the other hand, sector attractiveness is a performance variable that measures the relative attractiveness of the sector when compared with other ones, as explained in Chapter 5. This dissertation assumes that the attractiveness of the software sector is directly related with the revenue of their firms and is formalized by previous Eq. (6.9)

Sector attractiveness is a normalized value (0-1), the higher the better, which helps firms, private and public sector in making decisions about how to invest on innovative activities, following the next equations:

$$FRR = SRV * SAT * RIR \tag{6.50}$$

Where:
FRR = Firm's reinvestments
RIR = Reinvestment rate

6.2.5 Human Capital Submodel

The Human Capital submodel highlights the stocks of knowledge which are "within" the heads of employees (R&D and non-R&D within the firm) and other human capital from external sources (Figure 6.14).

Even though all variables and linkages have been explained in previous equations, it is important to highlight some aspects related with the interaction of human capital and the overall sectoral software system in Brazil.

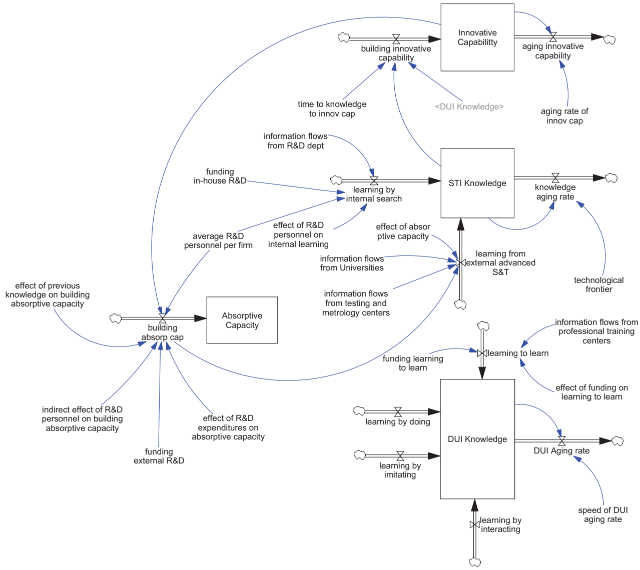

Figure 6.14: **Human Capital simulation model** - Source: Author

The first variable of interest is related with the effect of previous knowledge on building absorptive capacity, which relates to tacit and explicit knowledge that had been previously stored in the firm and that through human capital is builds upon absorptive capacity (Eq. (6.17) and Eq. (6.18)).

STI knowledge building is also influenced by human capital, which, through information flows from advanced S&T institutions such as Universities, Testing and Metrology Centers and also through R&D personnel engaged in R&D activities (Eq.(6.21) and Eq.(6.22)).

Finally, another variable of interest is related with the effect of information flows from professional training centers and training expenditures by firms, which rely on building DUI mode of knowledge (Eq. (6.26)).

6.2.6 Additional Model Parameters

In order to complete the design of the system dynamics model, i.e. the stock and flow model, additional parameters were included. Figure 6.15 shows the summary of such values:

As shown in Figure 6.15, technological frontier represents the current state of the frontier of knowledge in international terms, in other words, the

Variable	Value	Units
Technological Frontier	1500	Knowledge
Firms reinvestment rate	0.01	dimensionless
Firms rate of entry	0.2	dimensionless
Firms rate of exit	0.01	dimensionless
Price	N(100,10)	USD
Software products services per customer	N(50,5)	Products/customer

Figure 6.15: **Summary of additional model parameters** - Source: Author

highest level of knowledge available in the global sector. This parameter serves to be compared with the actual technological level of the software industry in Brazil, the resulting gap will represent the technological distance that needs to be reduced in order to maintain the rate of innovative activities.

Firms reinvestment rate represents the investments on continuous innovative activities as a percentage of sales revenue. This value was estimated for the whole software sectoral innovation system. Firms rate of entry and firms rate of exit represent the speed at which firms enter and leave the sector respectively.

Price represents the prices of software products commercialized in the market, in this case a random normal function was used, with $mean = 100$ and $stddev = 10$.

Finally, the number of software products and services per customer represents the amount of sales per customer (new and old). It was estimated using a normal function as well, with $mean = 50$ and $stddev = 5$.

6.2.7 Synthesis

This Section has described the design of the stock and flow model, based on the five components and linkages of the modeling framework of Section 5.2, on the definition of the core causal or feedback loops (Section

Each component of the modeling framework was translated and parametrized into stock and flow notation, by describing how each state variable (stock) was linked to each rate variable (flows). In addition each component and linkage was described in mathematical form by means of proposing a specific set of equations for each one of them. Even though the mathematical formalization may be subject to disagreements, each one of the proposed equations was based on previous equations from the literature, on data gathered from PINTEC and on additional data sources, leaving little room for subjective equation design.

Moreover, all links between components and feedback structures defined in Section 5.3 were formalized, which represents an additional contribution related with an even deeper understanding of the complex dynamics of innovation systems in general and of sectoral innovation systems in particular.

Models, at the same time, are poor representations of reality meaning that no single model will ever be truthful, as Sterman (2000) has pointed out elsewhere. In this sense, the model presented in this Section accounts for the first approximation on the use of complex modeling methods to approach the innovation systems domain, in other words, it represents the first iteration of a longer set of model refinement exercises, which are not taken into account in this dissertation.

Moreover, as suggested by Garavaglia (2010), the targets of such simulation studies are not explicitly formalized in the relationships, variables and interactions among these variables, rather, they emerge from the repeated computed nonlinear dynamics within the model.

Nevertheless, models in general and system dynamics models in particular have to be validated, in the sense that they need offer a certain degree of confidence to the modeler and to the model's users in terms of its outcomes. System dynamics models possess their own validity methods, as previously discussed in Section 3.1.4 and therefore, the next Section describes their results.

6.3 System Dynamics Model Validation

In order to gain confidence on the simulation model previously described, several tests were run. As described in Section 3.1.4 and 4.5, system dynamics possess specifically designed tests to build confidence on their models. The following Sections describe their results.

6.3.1 Structural validity tests

Structural tests have as main aim to check if the structure of the model is adequate for its purposes, they are described in Section 3.1.4. Several tests were run over the structure of the model and the results are shown in the following paragraphs.

Boundary adequacy: This test considers the structural relationships needed to satisfy the purpose of the model, verifying is the chosen endogenous, exogenous variables are adequate. Thus, the boundaries of the simulation model were defined by the modeling framework specifically designed for innovation systems (Section 5.2), thus, it can be right to say that this test has passed.

Structure verification: This test compares the structure of the model with the structure of the real system. In this sense, the structure of the model must not contradict the knowledge about the real system. Thus, similar to the previous test, the structure of the model was based on the modeling framework and on the literature review on innovation systems, therefore, the test has passed.

Parameter verification: This test aims at verifying the validity of parameters or constants used in the model and to compare them with actual knowledge about them, in order to determine if they correspond conceptually and numerically to reality. Thus, most parameters were taken from a specialized dataset on innovative activities in Brazil (PINTEC). Two versions were used, PINTEC-2005 and PINTEC-2008. Due to the characteristics of the PINTEC survey, categorical variables had to be recoded into normalized variables (scale from 0 to 1). Such parameters are presented in Section 6.1.

Other variables however had to be defined through educated guess which despite their acceptance as valid in the system dynamics literature - they do not represent the best option for model instantiation and calibration. In this sense, this test has been passed partially.

Dimensional consistency: The test verifies if the units used in the variables, parameters and constants of the model are sound and coherent. Thus, in order to check the units of variables, parameters and constants, a built-in functionality of Vensim DSS was used, called "Units check". The results reported dimensional consistency was ok, thus, the test has passed.

Extreme conditions: The test verifies if the model behaves in an irascible way when extreme values are defined for the parameters or variables. In other words, even when the model is set with extreme values, it should behave within the logic boundaries of the real system.

In order to perform this test, several tests were conducted as the model was designed. Since showing all of them would make this test description long and tedious, I opted out for showing two of them. First, I test the sensibility of the variable "technological frontier", which initial value was set to 1500 [dimensionless] as shown in Figure 6.15, to a higher extreme value of 8000 [dimensionless]. Technological frontier can be defined as "the highest level reached upon a technological path with respect to the relevant technological and economic dimensions" (Dosi, 1982).

This change would imply a huge gap between the technological level of the sector and the technological frontier, meaning that firms should have to engage in performing R&D activities and in acquiring external R&D in order to get closer to the frontier. Thus, the expected behavior would be a steeper growth of R&D expenditures, seeking to reduce the gap, the simulated behavior is coherent with it as shown in Figure 6.16.

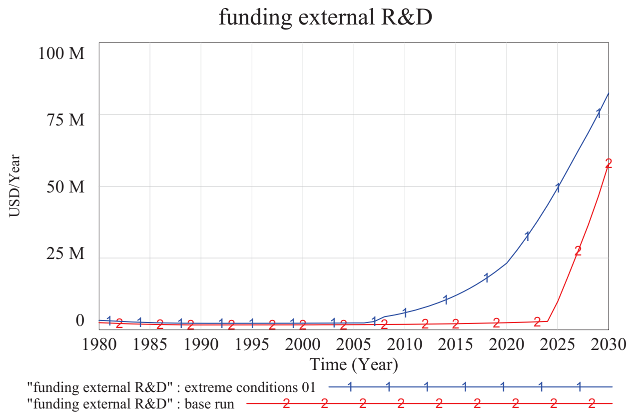

Figure 6.16: **Extreme conditions test 01 Large gap to technological frontier** - Source: Author

The second extreme conditions test is related with the effect of firms reinvestments on innovative activities. In this test, the reinvestment rate is set to 0.0 and the expected behavior would be a decrease in the stock of knowledge and innovative capability over time. Particularly, Figure 6.17 shows the outcome of the variable Innovative Capability, which is coherent with the initial expectations.

By observing the behavior of both extreme conditions test, this Dissertation assumes that the test has passed.

6.3.2 Behavioral validity tests

In terms of behavioral tests those concerned with comparing the model generated behavior with the real system behavior, the following tests were performed.

Integration error: This test verifies if there is any change in the behavior of the system when the integration step is altered, or when the integration method is altered.

Thus, we conducted two different sets of tests, the first one including a change in the integration step from $TIMESTEP = 0.5$ to $TIMESTEP =$

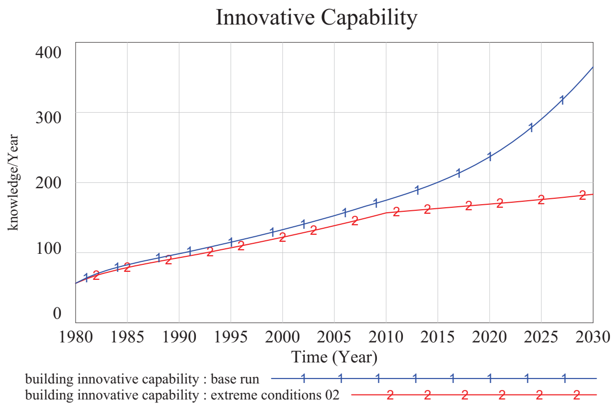

Figure 6.17: **Extreme conditions test 01 Decrease in firms reinvestment rates** - Source: Author

0.25. The second test, aims at changing the numerical integration method, from $Euler$ to $RungeKutta$. Figure 6.18 and 6.19 show the results of each test for the variable "innovative capability", showing that in both cases the results are highly similar, concluding that integration errors provide no significant bias in the model.

Behavioral reproduction: This test verifies if the behavior of the model is similar to the behavior observed in the real system.

In order to comply with this test, some comparative analyses were performed between simulation outcomes and data gathered from the Software Sector. Thus, data from sales revenues (real versus simulated) were compared, in order to check if similar behavior was present. Figure 6.20 shows real data from domestic sales (six data points), a forecast using an exponential regression, with R^2=0.9259 and a regression equation $y = 5e - 7 * e^{0.0853x}$ and the simulated results of sales revenue for the period 1980-2030.

According to the comparative results of Figure 6.20, it is concluded that the test has passed.

Behavior anomaly: This test is used implicitly during the model design and aims at identifying anomalies in the model behavior.

Throughout the modeling design process, the model was calibrated. Therefore, the model does not show anomalies in the simulated behavior.

Family member: This test verifies the capacity of scalability of the model to other realities or similar real systems.

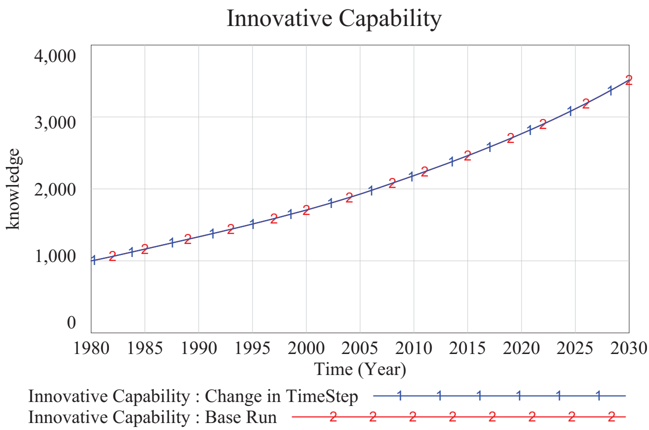

Figure 6.18: **Integration Error test Time step change to 0.25** - Source: Author

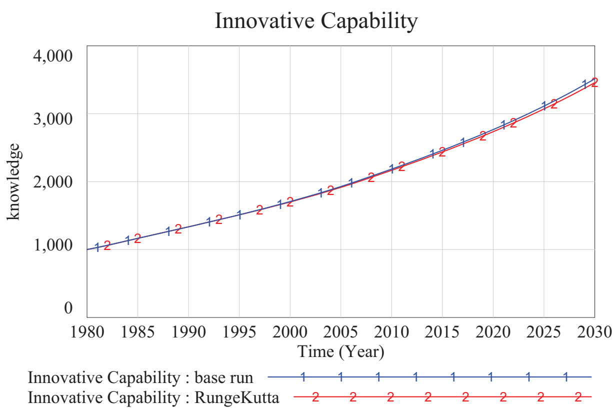

Figure 6.19: **Integration Error test Integration Method change to Runge Kutta** - Source: Author

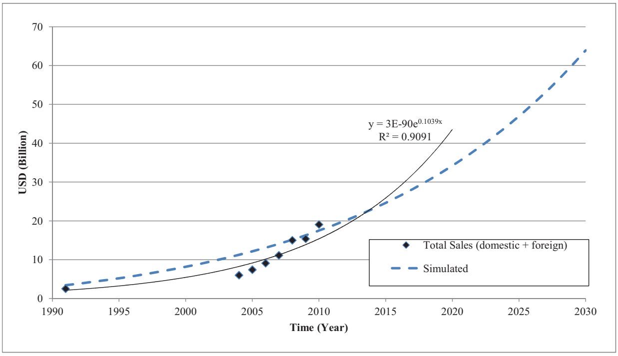

Figure 6.20: **Behavioral reproduction test Sales revenues real data and forecast** - Source: Author

Since the model was developed based on a generic modeling framework for innovation systems, it can be said that the model can be scaled upon other innovation systems instantiations: national, regional, sectoral, etc.

Surprise behavior: This test verifies if unexpected behavior is product of failures in model design or if they are actual behavior in the real system. This test also verifies the practical utility of system dynamics models when the second option is correct.

The model was calibrated and thus, any behavior it produced could be taken not as a failure in model design but as a part of the complex dynamics of the system modeled.

6.3.3 Synthesis

As shown in the previous Sections, several validity tests were performed. Those tests account for special validation processes within the system dynamics literature. First, structural validity tests proved that the overall structure of the model is adequate to its aim and purpose, since it was built based on the modeling framework introduced in Section 5.2. Second, out of the pool of structural tests, the only one that passed in a partial way was "parameter verification" due to the use of data from only two points in time, specifically, PINTEC editions 2005 and 2008. However, as recent studies have suggested, there is a lack of time series datasets related with innovative activities (Castellacci and Natera, 2011), which in fact was the main reason to use PINTEC in the first place.

Then, behavioral validity tests were performed, by observing how the model behaved to changes in boundary and parameter conditions, such as integration method change and integration time step and later, model simulated behavior was compared with real data from the Software Sector. First, the group of behavioral tests aimed at looking for changes in boundary and parameter conditions proved that there were no significant changes in the overall behavior of the model when such values were changed. Second, the group of tests aimed at testing the consistency of the model by comparing their results with actual data, proved that the model is consistent with the behavior actually observed in the real sectoral system.

Thus, based on the results of both types of validity tests, is concluded that the model is consistent with the actual sectoral system behavior and therefore it is adequate to run simulation experiments related with the objectives of this dissertation, however observing that as new data sources come up, new and even better tests can be performed. This is the case of partial model validation tests, suggested by Homer (1983) and model calibration as strategies for model validation suggested by Oliva (2003).

6.4 Simulation Experiments

In this Section, four simulation experiments were conducted in order to observe the dynamics of the Software Sector in Brazil, by testing different conditions in which firms' innovative activities takes place, namely: properties of the knowledge base, technological opportunities, appropriability conditions, and cumulativeness conditions. Data used for each experiment is found on Section 6.1.

Each experiment is composed of several simulation runs aiming to visualize the sensibility of the system to particular variables and how they affect the behavior of the whole system. At the same time, the structure of each experiment follows a short description of what is the experiment, a theoretical explanation of why each experiment is important, and ends up with some comments related with their results.

6.4.1 Testing different rates of learning processes in knowledge bases

Experiment Relevancy

Knowledge plays a central role in innovative activities and is accumulated by different types of learning and capabilities (Malerba and Nelson, 2011). At the same time, previous chapters have shown that there are two types of knowledge, and thus, two types of knowledge base: science, technology and innovation (STI) knowledge, and doing, using and interacting (DUI) knowledge.

Different learning rates also affect the way firms accumulate knowledge, and therefore the overall dynamics of the sectoral system. In this sense, a simulation experiment testing different rates of learning and their effects on the sectoral innovation system may be of interest.

Experiment Aim and Procedure

Specifically, the second experiment aims at testing how different rates of learning affect the dynamics of the software sectoral innovation system. Learning activities are modeled as flows that head on to STI knowledge base or to DUI knowledge base, depending on the type of learning. DUI knowledge base is composed by four learning inflows: learning to learn, learning by doing, learning by interacting and learning by imitating (See Section 6.2.3). On the other hand, STI knowledge base is composed by two learning inflows: learning by internal search and learning from external advanced S&T (See Section 6.2.2).

The speed of each learning flow is a function of the relative importance of that learning type, and as a function of the amount of financial capital invested Section 6.2. Thus, I first test the effects of different learning rates on STI knowledge by changing the relative importance of learning by imitating, doing, interacting and learn activities and by changing the importance of several information flows. Based on data extracted from PINTEC (See Section **??**sec:instantiation), the values of relative importance for innovative activities and relative importance of information flows are summarized in Figure 6.21:

Knowledge Base	Learning Type	Variable	Acronym	Value for year 2005	Value for year 2008	Units
STI Knowledge	Learning by internal search	Importance of in-house R&D	IIR	0.29	0.16	Dimensionless
		Inf Flows from R&D Dept.	FIR	0.41	0.52	Dimensionless
	Learning by external advanced S&T	Importance of external R&D	IER	0.02	0.03	Dimensionless
		Inf. Flows from Universities	FUR	0.10	0.15	Dimensionless
		Inf. Flows from Testing Centers	FTR	0.06	0.12	Dimensionless

Figure 6.21: **Parameters for STI knowledge base** - Source: Author

As shown in Figure 6.21, in-house R&D (IIR) has a higher relative importance than external R&D (ERD). Similarly, the most important information flows are described as coming from the internal R&D departments (FIR), therefore, according to data from PINTEC, the software sectoral system in Brazil is highly intensive in performing in-house R&D.

The following changes will be applied: Run01 will increase the importance of external R&D activities and accordingly, the importance of external R&D information flows by 25% each. In turn, the relative importance of in-house R&D and of information flows from R&D Departments will be decreased by 25%. Run02 will test a steeper change, by increasing the importance of external R&D by 50% and by reducing the importance of in-house R&D by 50% as well. Finally, Run03 will test a scenario when both in-house and external activities have the same importance as summarized below.

Run 01 in-house R&D increase by 25% - external R&D decrease by 25%
Run 02 in-house R&D increase by 50% - external R&D decrease by 50%
Run 03 in-house R&D and external R&D share the same importance

The next three simulation runs test the effects of different learning rates on DUI knowledge by changing the relative importance DUI-related learning activities. Based on the data from Section 6.1, the values of relative importance for innovative activities and relative importance of information flows on DUI are summarized in Figure 6.22:

Knowledge Base	Learning Type		Variable	Acronym	Value for year 2005	Value for year 2008	Units
DUI Knowledge	Learning by doing		Inf. Flows from other knowledge	FOP	0.35	0.41	Dimensionless
			Importance of other technical prep.	IOP	0.12	0.21	Dimensionless
	Learning by imitating		Inf. Flows w/competitors	FCM	0.27	0.26	Dimensionless
			Inf. Flows from patents, etc.	FPM	0.29	-	Dimensionless
			Importance of other knowledge	IOK	0.15	0.13	Dimensionless
	Learning to learn		Importance of training	IWT	0.38	0.37	Dimensionless
			Inf. Flows from training	FWT	0.08	0.10	Dimensionless
	Learning by interacting	Suppliers	Inf. Flows from suppliers	FSU	0.31	0.24	Dimensionless
			Importance of suppliers	ISU	0.35	0.33	Dimensionless
		Customers	Inf. Flows from customers	FWC	0.39	0.45	Dimensionless
			Importance of tech innov for the market	IWC	0.14	0.29	Dimensionless
		Others	Inf. Flows from consulting, etc.	FWO	0.14	0.23	Dimensionless
			Inf. Flows from Conferences, Publications, etc	ICP	0.19	0.26	Dimensionless
			Inf. Flows from fairs and expositions	IFE	0.19	0.20	Dimensionless

Figure 6.22: **Parameters for DUI knowledge base** - Source: Author

Comparatively, the relative importance of DUI-related learning activities is higher than those of STI. At the same time, the categories with higher importance levels are customers, training activities and other knowledge (from other internal departments). Thus, Run04 will increase the importance of information flows from customers by 25%, leaving all others fixed; Run 05 will increase the importance of information flows from training activities by 25%, leaving all others fixed; and Run 06 will increase the importance of information flows from other knowledge from within the firm by 25%, leaving all other fixed, as summarized below.

Run 04 increase in the importance of information flows from customers by 25%,
Run 05 increase in the importance of information flows from training activities by 25%,
Run 06 increase the importance of information flows from other knowledge by 25%

Experiment Results

Figure 6.23 shows that changes in learning rates related with R&D. Specifically, when the same importance level is given to both in-house R&D and external R&D (Run03) the knowledge accumulated in STI mode shows a decay in the long run. On the other hand, Run01 and Run02 do not show great differences in the overall behavior of the system, even though they show a slight oscillatory behavior, the system does not show evidence to conclude that it is sensible to changes in increases in in-house R&D and decreases in external R&D.

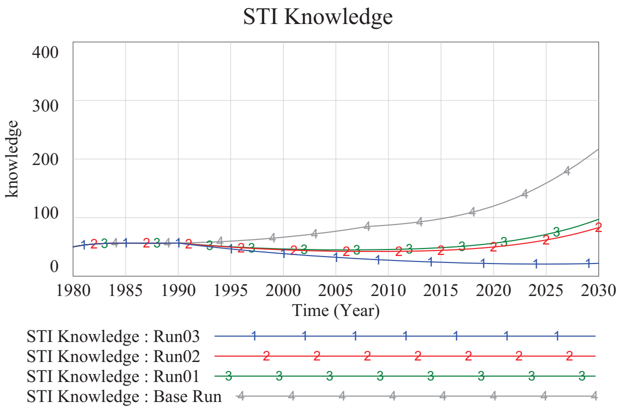

Figure 6.23: **Experiment 01 STI Knowledge and different learning rates** - Source: Author

On the other hand, results from Run04, Run05 and Run06 (Figure 6.24), do not show significant differences, meaning that the system is not sensible to single changes in the use of customers, training activities and knowledge from other departments alone.

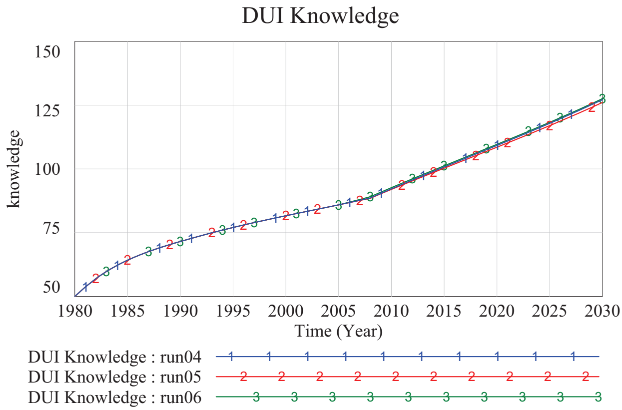

Figure 6.24: **Experiment 01 DUI Knowledge and different learning rates** - Source: Author

6.4.2 Testing different levels of technological knowledge opportunities

Experiment Relevancy

Technologically advanced sectors have been traditionally linked with high levels of opportunity conditions. Moreover, such conditions are believed to be positively correlated with the rate of performance improvement over time (Castellacci, 2007). However, literature has also suggested that high levels of technological opportunities are not constant, i.e. high opportunity levels may be related to the early stages of a sector, while, low opportunity levels, related to later stages in the development of the same sector (Malerba and Orsenigo, 1993). Literature has also suggested that opportunities are built through three sources: advances in scientific knowledge STI knowledge building, technological advances in other industries (spillovers) some types of DUI knowledge building, and positive feedbacks from the sectors own technological advance (Klevorick et al., 1995).

In this sense, it is important to know how different source levels of opportunity conditions affect the overall behavior of sectoral systems and specifically the software sector in Brazil.

Experiment Aim and Procedure

This experiment aims at testing how different levels of technological opportunities impact on the overall dynamics of the sectoral software system in Brazil. Technological opportunities are described by the ease with which new or improved solutions to problem solving activities are found (Castellacci, 2007).

From a more operational perspective, the levels of technological opportunities can be changed by changing the levels of their sources, namely: the degree of external STI knowledge, the degree of external DUI knowledge and the degree of internal accumulated knowledge. In this sense, the following simulation runs will correspond to such changes. First, Run01 will set an increase in 50% on the importance of information flows from universities, and 50% increase on the importance of information flows from testing centers (initial values were taken from Section 6.2.6). Run02 will set a decrease in 50% on both previous opportunity sources. Run03 will set an increase in 50% on the importance of information flows from suppliers and Run04 will set a decrease of 50% on the importance of information flows from suppliers.

Run 01 increase on the importance of information flows from universities by 50% and increase on the importance of information flows from testing centers by 50%
Run 02 decrease on the importance of information flows from universities by 50% and decrease on the importance of information flows from testing centers by 50%
Run 03 increase on the importance of information flows from suppliers by 50%
Run 04 decrease on the importance of information flows from suppliers by 50%

Experiment Results

Figure 6.25 and Figure 6.26 show the results from Experiment 02. Specifically, Figure 6.25 shows the changes in external S&T when there is an increase by 50% on the importance of information flows from universities and testing centers (Run01) and a decrease of both by 50% (Run02). Run01 shows an exponential growth pattern, which could be expected after such an increase, Run02 however shows an interesting result, less expected, which is that even if there is a decrease of 50% in key variables, even if the shock represents a change in the pattern of behavior, the system itself regains speed and after a few decades it has completely recovered towards the value initially set before the shock was produced.

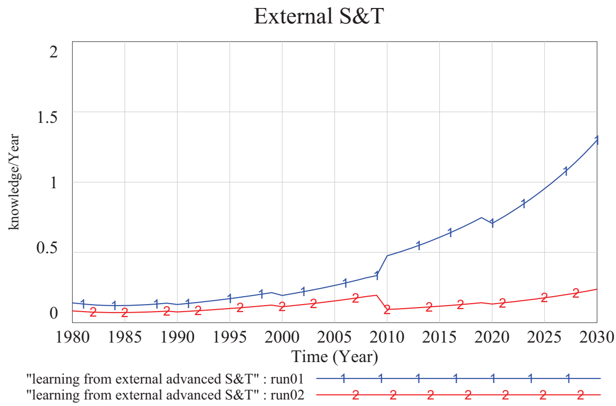

Figure 6.25: **Experiment 02 Technological opportunities and external S&T** - Source: Author

Figure 6.26 follows the same logic, by showing that for Run03 and Run04, even when there are shocks of considerable magnitude (50% increase in the former and 50% decrease in the latter), the system self-adjusts to recover a slight yet clear exponential growth.

6.4.3 Testing different levels of knowledge appropriability conditions

Experiment Relevancy

Appropriability conditions refer to the ease with which innovations can be protected from imitation (Malerba and Orsenigo, 1993). If the level of appropriability within a sectoral system, is high, non-innovative firms will find difficulties in imitating innovations, however innovative firms will also find difficulties in learning by imitating activities. At the same time, if levels are low, the market may get saturated very fast, since innovations are rapidly imitated and diffused throughout the market. In sectors with higher levels of appropriability conditions, it is expected to observe greater incentives in investing on innovative activities: an incentive effect on firm behavior. On the other hand, when the level of appropriability is low, it is

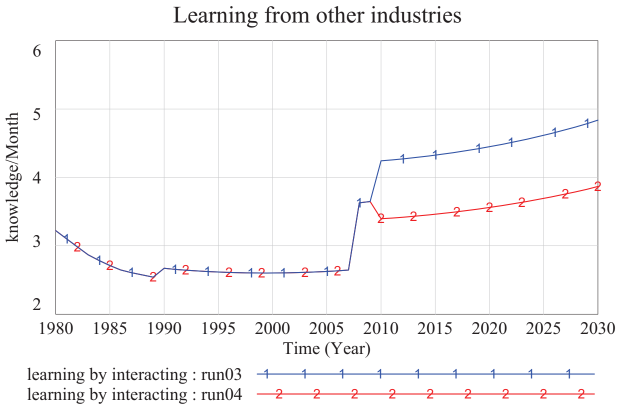

Figure 6.26: **Experiment 02 Technological opportunities and learning from other industries** - Source: Author

expected to observe a higher level of imitation and intra-sector knowledge diffusion: an efficiency effect (Castellacci, 2007).

However, appropriability is difficult to measure directly, and what has been done through traditional methods has been to investigate it indirectly and qualitatively by examining the effectiveness of various means of appropriability (Harabi, 1995). Thus, simulation may provide additional insights on testing how appropriability conditions impact on the dynamics of the software sectoral innovation system.

Experiment Aim and Procedure

These simulation-runs aim at testing how different levels of appropriability conditions impact on the overall dynamics of the sectoral software system in Brazil. From a modeling perspective, appropriability conditions can be regarded as changes in the rates of learning by imitating one of the learning activities used by firms to accumulate DUI knowledge. Learning by imitating represents the degree at which a firm learns from patents, licenses and competitors.

Specifically, learning by imitating is a function of information flows from competitors (through reverse engineering and other imitating mechanisms), information flows from the acquisition of patents, licenses and so on, and of the level of importance of other external knowledge for the firms innovative activities. In this sense, Run01 will increase the level of information flows from competitors, patents and the level of importance of other external knowledge, by 25%. Run02, will show a steeper increase of 50% on the same variables, and finally, Run03 will show a decrease of 25%.

Run 01 increase in learning by imitating by 25%
Run 02 increase in learning by imitating by 50%
Run 03 decrease of learning by imitating by 25%
Run 04 decrease of learning by imitating by 50%

Experiment Results

Figure 6.27 shows the results of the four simulation runs for the variable DUI knowledge. Some considerations can be made, first, all four runs show the same pattern of behavior, with slight differences but very similar to each other; second, increases in the rate of learning by imitating and decreases on the same rate showed expected behaviors, i.e. increases yielded to higher growth rates and decreases yielded to lower ones.

Thus, for the software sectoral innovation system, increases or decreases in the rates of imitating activities will still play a minor role on the overall behavior of the system.

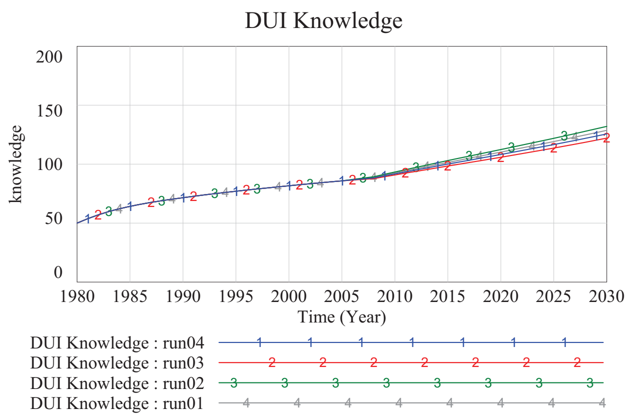

Figure 6.27: **Experiment 03 Appropriability conditions and DUI Knowledge** - Source: Author

6.4.4 Testing different levels of knowledge cumulativeness conditions

Experiment Relevancy

Cumulativeness conditions are related with the extent to which current innovative activity builds upon previous knowledge (Malerba and Orsenigo, 1993; Castellacci, 2007). It has been suggested that cumulativeness variations have a direct effect on searching activities (Dosi and Nelson, 2010) and therefore on the capacity to increase innovative capability. The property of cumulativeness helps to gain insights on why new firms may or may not enter new markets, on why innovative capability in specific sectors grows faster than in others, and on how knowledge cumulativeness may dictate the dynamics of the overall sectoral system.

Thus, an experiment simulating different levels of cumulativeness may help in shedding light in the issues raised previously, specifically, on how accumulated knowledge may alter the behavior of the software sectoral innovation system.

Experiment Aim and Procedure

The aim of this experiment is to test how knowledge helps in building up new innovative capability through changes in the levels of cumulativeness conditions. From a modeling perspective, cumulativeness levels are represented by the stocks of STI knowledge and DUI knowledge, which are used to build up innovative capability. By testing changes in the level of both knowledge stocks and their impact on innovative capability, changes in the overall behavior can be observed.

In this sense, Run01 will reduce the effect of STI knowledge on innovative capability by 25%. Run02 will increase the same parameter by 25%. Run03 will reduce the effect of DUI knowledge on innovative capability by 25% and Run04 will increase the same parameter by 25%.

Run 01 effect of STI knowledge on innovative capability decrease of 25%
Run 02 effect of STI knowledge on innovative capability increase of 25%
Run 03 effect of DUI knowledge on innovative capability decrease of 25%
Run 04 effect of DUI knowledge on innovative capability increase of 25%

Experiment Results

Figure 6.28 shows the results of Experiment 4 on the variable Innovative Capability. In this experiment, the software sectoral innovation system responds as sensitive to changes in the rates of knowledge cumulativeness. Even though increases in the rates yielded to expected higher growth rates in innovative capability, decreases did not, as they yielded lower yet clear growth rates.

In this sense, some considerations can be made. First, the software sectoral system is moderately sensitive to changes in the rates of cumulativeness, when compared with results from former experiments, where moderate and even large changes produced almost no difference in the results. Second, cumulativeness in software activities is valuable in the sense that previous knowledge is a key element to build up new one. Third, as previous experiment on appropriability conditions have shown, the software sector is particularly subject to use the firm‘s own knowledge sources rather than to look for others in competitors or even patents and licenses.

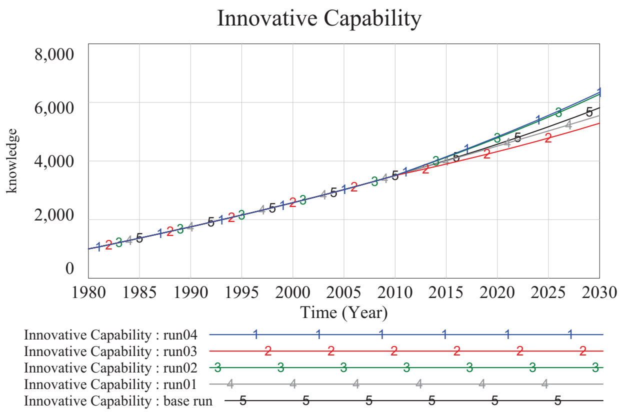

Figure 6.28: **Experiment 04 Cumulativeness conditions and Innovative Capability** - Source: Author

6.4.5 Synthesis

Simulation experiments such as the ones introduced in this chapter are motivated by the desire to develop theoretical explanations capable of dealing with the complexity of innovative activity. Even though no single model captures all the dynamics and complexity of innovation systems, the previous experiments have helped in showing the relevance and usefulness of the model proposed in this Dissertation.

Four experiments were performed, each testing a specific condition of the software sector's technological regime, namely, technological opportunities, properties of the knowledge base, appropriability conditions and cumulativeness conditions. All four experiments showed how changes in key variables do have predictable and unpredictable effects on the overall behavior of the innovation system, namely, their growing, balancing, logistic and oscillatory patterns of behavior.

First, a necessary (but not sufficient) condition for the software sectoral innovation system to show a pattern of exponentially growth is the persistent increase of technological opportunities of innovation. Second, innovation stems from the interplay between different types of learning and knowledge accumulation, since different rates of learning produce different dynamics within the sectoral system. Third, no significant effects were evidenced as caused by imitating activities, suggesting that appropriability conditions may not be critical for the development of the software sector in Brazil. Fourth, because there is no evidence of significant effects from imitating activities, the sector basically builds up its knowledge base from the cumulativeness conditions in which they perform their activities, by using other searching mechanisms, both based on the accumulation of knowledge to build new one.

As a final consideration, it can be said that the model can be used to perform infinite sets of alternative simulations by experimenting with different changes and by observing their impact on the system. The experiments described above proved to capture the dynamics behind the components and linkages identified in the literature by showing the complex behavior produced by changes in different sets of conditions and represent only a pilot study out of which new and improved versions may come out. Moreover, the experiments performed in this section have helped in shedding more light on how knowledge and learning processes affect the overall dynamics of the Software Sectoral Innovation System in Brazil.

6.5 Concluding Remarks

This chapter has presented the formalization of the model, by using a simulation modeling method, i.e. system dynamics, based on the instantiation for the case of the Software Sector in Brazil.

Specifically, the stock and flow diagrams were formalized by using differential equations. Those equations were based on the review of previous models, on data from PINTEC and ultimately, when data lacked, from educated guesses based on the qualitative knowledge of the system.

Furthermore, the model proved to capture the dynamics behind the components and linkages identified in the literature by creating an explicit relation between quantitative and qualitative data of innovation systems and by using it to gain additional insights about the dynamic behavior of such systems and specifically about sectoral dynamics.

7

Conclusions and Future Work

This dissertation aimed at improving the understanding of how knowledge and learning processes affect the dynamics of innovative activities. In order to fulfil the previously described objective, this dissertation designed a system dynamics simulation model, based on a new modelling framework, on the analysis and description of circular causation mechanisms, and on the mathematical formalization of data from PINTEC and other sources.

The first part of this chapter presents the final conclusions of the research, discussing the main findings, contributions and shortcomings of the work and the last section, presents some suggestions for future work based.

7.1 Conclusions

A large set of previous models of innovation systems were systematically reviewed and classified into four groups: conceptual models, system dynamics models, econometric models and others. The first conclusion of this Dissertation showed that there is a large amount of models and modeling approaches, which evidence that there is no consensus or agreement on a specific set of components and linkages composing an innovation system.

Although it may be argued that the variety of models and modeling approaches are specific to each study and that in fact their diversity enriches the innovation systems literature, the vast number of models previously proposed in the literature makes the decision - of choosing a specific one for a specific purpose - harder. Moreover, each model is no more than a poor abstract representation of reality, and therefore, subject to bias, lack of knowledge and subjectivity, which may lead to choose a less appropriate one.

Thus, a broad and exhaustive review of previous models may help in finding some commonalities among them, that could help in grouping or clustering them in a more formal and logical way. After a careful review of such models, this Dissertation evidenced that each group highlighted specific elements and linkages of specific parts of innovation systems. The second conclusion of this work was related with the former statement.

Therefore, one of the main specific contributions of this research was to propose a new framework, that could synthesize the main components and linkages of previous literature, a framework that would serve to design future specific models for specific purposes yet with less bias and subjectivity, due to its foundations on a large set of previous literature, a framework that would prove to be equally valuable, at least, than the vast diversity of models out there.

Based on the systematic review, this new modeling framework was proposed. As previously discussed, the modelling framework synthesizes a large amount of previous models and proposes a unique yet complete set of components and linkages that can be used to describe innovation systems and moreover, to model them. Those components are Financing and Funding component, a Science and Technology component, a Technological Production component, a Consumer Market component and a Human Capital component.

The third conclusion of this Dissertation is related with the usefulness of the framework, specified on its ability to identify the different types of learning activities that affect the dynamics of innovation systems and the two types of knowledge, STI knowledge and DUI knowledge, which are the main knowledge accumulation mechanisms within an innovation system.

Afterwards, the modeling framework was used to define the causal relationships and the feedback loops that define the reinforcing and balancing forces within the innovation system, when designing the causal loop model. It was concluded that the causal loop model shows that the components of an innovation system are basically linked by circular causation mechanisms which produce learning and knowledge accumulation, and that they drive the behavior of the system, by encouraging the dominance of some learning loops over others, becoming the fourth conclusion of this Dissertation.

Since the framework describes in a detail way how knowledge and learning processes are linked with and affect the innovation system, from a conceptual perspective, in other words, it links knowledge and learning with the innovation system from a static and descriptive perspective, the next contribution of this Dissertation was the design of a comprehensive model which could be used to observe the dynamics within the innovation system.

In this sense, a system dynamics simulation model was built based on the modeling framework and on the causal relationships from the CLDs. In addition, data from PINTEC the Brazilian Technological Innovation survey was used to calibrate the model. Differential equations were proposed to mathematically formalize the simulation model which were formulated based on the review of previous models, on data from PINTEC and ultimately, when data lacked, from educated guesses based on the qualitative knowledge of the system.

Since there are no current datasets that group at least a moderate number of indicators in the form of time series for a relatively long period of time, this Dissertation opted in using data from the PINTEC surveys, which represent the largest and broadest dataset on innovative activities in Brazil, its major advantage. In this sense, data from the last two editions, PINTEC-2005 and PINTEC-2008 were analyzed and specific categories were selected. The major shortcoming of PINTEC is, however, that it does not offer enough data to build time series and therefore to estimate parameters and behaviors in a more accurate way, since only the two last editions accounted for software activities. Still, data collection proved to be adequate for the purposes of this Dissertation, and additional data sources and calculations are left for future studies.

Each component of the modeling framework was translated and parametrized into stock and flow notation, by describing how each state variable (stock) was linked to each rate variable (flows). In addition each component and linkage was described in mathematical form by means of proposing a specific set of equations for each one of them. Even though the mathematical formalization may be subject to disagreements, each one of the proposed equations was based on previous equations from the literature, on data gathered from PINTEC and on additional data sources, leaving little room for subjective equation design. The mathematical formalization represents an additional contribution of this Dissertation, which dares to formalize although in a simple form the complexity of the relationships within an innovation system, thus I conclude that the simulation model is adequate to represent innovation systems and the software sectoral innovation system in particular.

Even though additional work may be developed in future studies, in building more explanatory yet more complex equations to increase the precision and accuracy of the previously mentioned equations, the set of equations presented in this work do contribute in increasing the understanding of the complex dynamics of innovation systems in general and of sectoral innovation systems in particular. Furthermore, I tried to use the mathematical formalization as less as possible, highlighting instead the relationships and effects between variables in a more approachable language.

Several experiments were conducted on the model in order to test the behavior of the system by changing the levels of technological opportunities, appropriability conditions, knowledge base complexity and cumulativeness conditions. Such experiments proved to capture the dynamics behind the components and linkages identified in the literature by showing the complex behavior produced by changes in the above mentioned conditions, namely, their growing, balancing, logistic and oscillatory patterns of behavior. As a final contribution, this Dissertation as a whole has shown to allow a better understanding of the complex dynamics behind innovation systems and of the software sectoral innovation system in particular, by proposing explicit linkages between a new and complete set of components, and by their instantiation into causal loop model and stock and flows model. In this sense, the simulation model presented in this Dissertation can be used to gain more insights about innovation systems and specifically, about sectoral dynamics.

Finally, this research has dealt with one of the main subjects inside innovation systems literature, which is to understand how innovation systems respond to interventions and therefore, on finding ways to properly manage innovation by considering their complexity in terms of dynamics, nonlinear relationships and complex behavior.

7.2 Future Work

During the development of this research, several items have been identified that could serve to conduct new and additional work, some of them are outlined in the following paragraphs.

As most sciences and scientific fields, the innovation systems field is an evolving one, in this sense a new and updated systematic review might help in finding out new studies proposing models in the literature and in gaining new insights about the proposing components and linkages.

Still in terms of the systematic review, additional databases can be used in forthcoming studies to identify a broader set of literature, since this Dissertation only focused on the arguably most mainstream databases in the scientific community. In this sense, by looking over non-mainstream databases, future studies may benefit in grasping a large set of more radical or less conservative - modeling approaches. In terms of the framework, additional work in the study of its components and linkages may yield to a refinement of specific sets of micro, meso and macro relationships. The framework in this sense, may serve as the basis for such new line of study.

In terms of causal loop models, additional work on refining the micro, meso and macro relationships on the modeling framework may also serve to refine the reinforcing and balancing loops, which may also help in increasing the explanation power of this model.

In terms of data collection, new sources of data in the form of time series may help in increasing the explanation power of the model developed in this work. Although there are no current data sources available to be used in this manner, I am aware of on-going research that is pointing towards this goal, specifically, the PhD work of Jose Miguel Natera from Universidad Complutense de Madrid, in Spain. Therefore, additional data sources and calculations are left for future studies.

Finally, additional future work may be developed in building more explanatory yet more complex mathematical equations to increase the precision and accuracy of the previously mentioned equations. Again, the accuracy of such equation modeling will depend on the quality of available data at the time, therefore, leaving this design for future studies as well.

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APÊNDICE B – Modelo de carta de solicitação de estudos adicionais aos autores (Primeiro Email)

Dear Dr. [Name of Author],

Our joint group composed by the [Our affiliated institutions] is conducting a *systematic review on the modeling of innovation systems*, and during this search we included your article entitled *[Title of Study]* As part of our review protocol, we are now contacting you as an expert in the field, to request information on other references that you believe might be included in our review. Specifically, are you aware of any other publications that might have been published after your paper in this field that would meet the following criteria:

1) The studies include a model (mathematical or conceptual) to explain/analyze/study innovation systems (IS).
2) The studies might use a model (mathematical or conceptual) to explain/analyze/study a sub-system of the IS or a specific relationship between two or more actors (i.e. industry, university, government, etc.).
3) The focus should be at the 'IS' level.

We highly appreciate your time in providing this information to us.

Sincerely,

[Authors of the research]

APÊNDICE B – Modelo de carta de solicitação de estudos adicionais aos autores (Segundo Email)

Dear Dr. [Name of Author],

A couple of months ago we contacted you referring a study I am leading in relation to the modeling of innovation systems, with [our affiliated institutions] researchers.

The first phase of our study retrieved a list of [X] papers, including your study [Title of Study], which proved to be relevant on our searches and in accordance to our research protocol we are asking you of any additional paper/book or other reference that you think might be relevant for our work.

The complete list of the [X] papers is posted here: http://bit.ly/SRuriona , the papers can be also downloaded. We think they might be of interest to you,

We highly appreciate your help,

Sincerely,

[Authors of the Research]

APÊNDICE C – The Software Sector in Brazil

CONTENTS

1.1 INTRODUCTION

> *The computer software and services industry is a key example of knowledge production, as the value of what a software company produces is almost entirely in the knowledge embodied in its products and services (UNCTAD, 2002).*

In recent decades, there has been an increasing interest on the so-called Knowledge Intensive Business Services (KIBS) and their role as servers of other high-tech and low-tech industries. KIBS produce intangibles, which are knowledge-intensive in nature and which require high levels of qualified staff and usually low levels of capital goods (Miles, 2005, Miles et al., 1995, Muller and Doloreux, 2009). Within the KIBS sectors, the Software Sector is one of the most innovative and dynamic industries in developed economies and in some catching-up economies as well (DTI, 2003, Tether and Swan, 2003, Niosi et al., 2012a).

Software production and its related Information Technology services are knowledge-intensive, since knowledge is the most critical competitive factor in the sector, becoming the main generator of competitive advantages through technological innovation. In this sense the Software Sector has experienced market reconfigurations, due to the appearing of new products, niches and segments. As a result, new incumbents have entered into the market, previously dominated by developed countries such as the United States, among them, India, China and other Asian countries but more recently, Latin American countries such as Brazil as well.

Many studies have shown the presence and extent of the role of the software industry in economic performance and in the competitiveness of regions and nations (Miles, 2004, Antonelli, 2000, Tomlimson, 2000) and this Appendix proposes to show a detailed analyses of the Brazilian Software Sector, with the aim to gain insights from its structural characteristics and innovative performance.

1.2 THE SOFTWARE SECTOR: METHODOLOGICAL AND COMPARABILITY ISSUES

Software products and related services are complex in nature. They rely on expert knowledge and on a specialized knowledge base to be developed (Malerba and Nelson, 2011), they also rely on highly creative stages - conceptualization, requirements analysis and high-level design – and specialized related services - consulting, training and software set-up, operation and maintenance. Such broad field of expertise and applications, often make statistical measurements difficult, in the sense that identifying all of these variables with limited time and other resources is a challenging task.

Secondly, software is of intangible nature. There is packaged software, custom software, software-as-a-service, embedded software, cloud computing and so on, which brings the problem of variability in the treatment of software statistics. This means that different countries may treat different groups of software activities in their national statistics which may not necessarily be of equal representation in another country, making the comparability issue a delicate and caution-like one (Lippoldt and Stryszowski, 2009).

Another issue to take into account is that literature proves that often software firms use non-traditional approaches to development, production and distribution of their products (Lippoldt and Stryszowski, 2009), leading us to a third issue: lack of data for non-traditional approaches and for in-house software not meant for commercial distribution outside the firm. In this sense, international comparability of non-traditional approaches might be flawed and also the accounting treatment of software investments.

All of the issues above, produce several constrains from a methodological perspective, that difficult a more standardized measurement of software activities, arising a lack of internal knowledge about the software sector within nations and regions, and also a lack of comparability indicators with other countries and regions, due to the lack of standardized measurements.

Thus, it can be argued that current data and related statistics on the software sector are either aggregated within broader sectors, such as the Information and Communication Technologies (ICT) Sector; within similar sectors, such as Software and related IT services Sector; and within supplemental sectors, such as Computers and related services Sector.

In the following pages, the analysis of the software sector from a global and from a local (Brazil) perspective, will be done by using the most appropriate and available sources of information, which in some cases will contain statistical data on broader or narrower sectors rather than on the specific software sector.

Although data on related and similar broader sectors could not be used to assess the state of the software sector in particular, at least, it could offer insights about how broader sectors are doing (in which software sector is part of), and therefore, they could be used to make general inferences on the software sector as well.

In the following section, I will introduce and overview of the software sector from a global perspective (global players, internationalization, etc.).

1.3 THE NATURE OF SOFTWARE

From a classical point of view, the OECD (1985) defined software as a structured set of instructions contained in different types of physical supports, with the aim to use electronic data processing equipment, generating intangible products. More recently, Lippoldt and Stryszowski (2009) had suggested a slightly different definition, for the authors, software is viewed as a set of digital instructions and operating information contained in programs, which are meant to guide machines in implementing desired operations.

From a software architecture point of view, software can be classified into three types: applications, operating systems and middleware (Lippoldt and Stryszowski, 2009). Applications are programs that interact with the final user; they may reside locally or remotely on work over a second layer, an operating system (OS). Operating Systems manage hardware resources, they are the responsible for serving as the interface between the user and the hardware; some examples are Windows, OS X or Linux among others. Finally, middleware serves as a intermediate layer between programs and operating systems, and provides interoperation of applications between different platforms.

More recently, other software categories have gained attention: cloud computing, software-as-a-service (SaaS) and embedded software. Cloud computing is a paradigm where applications, programs, platforms or other software types are accessed by users over the internet and managed by external providers on remote servers (Ryan, 2011). Software as-a-service (SaaS) is a paradigm where the user or customer pays the use of the software as it is using it, rather than paying it upfront as a package; in this case, software is stored and maintained by the SaaS provider (remote servers). Finally, embedded software resides on a long-term basis in hardware units such as cell phones, medical devices, consumer electronics and others.

Additionally, software products can be classified into packaged software, custom software and in-house software (Britto and Stallivieri, 2010, Lippoldt and Stryszowski, 2009). Packaged software has a relatively high degree of standardization, which can be used – unchanged or with minor changes – by a wide variety of users; they can be of "universal" nature (such as word processors), aimed to mass markets; and business solutions, which require some adaptation to user needs (such as ERPs or CRMs). Custom software is software developed specifically for a costumer. In-house software is software that is developed within a firm or organization to fill its own needs.

It is worth noting that in Brazil, the Softex Association adopts the following classification: packaged and custom software, high and low value added services, and embedded software (Britto and Stallivieri, 2010). Those types are included in the previous classifications described above.

1.4 AN OVERVIEW OF THE GLOBAL SOFTWARE SECTOR

Total worldwide spending on the macro ICT Sector was estimated to be 3398 Bi [USD] in 2009 out of which 305 Bi [USD] was from software with an annual growth rate of 7.3% (OECD, 2010, ABES, 2011).

The software sector is one of the most profitable sectors in the world. In a OECD study including the top 250 ICT firms in the world, software proved to be one of three ICT sectors with profits in the period

2000-2009, with an average value of 21% (OECD, 2010). The study showed as well, that software firms were in second place of R&D intensity (share of average revenue), with an average value of 15%.

From a global perspective, the industry leaders remain in developed countries. OECD (2010) shows that the top ten software firms in the world are all from the United States, Europe and Japan. Among them, Microsoft, Oracle, Symantec, Electronic Arts, Google, Amazon, eBay, Yahoo, from the United States; United Internet and SAP from Europe; and Konami from Japan.

However, over the past decade many developing countries, most of them from Asia, have catch up and gained a competitive position among the main global actors in three different waves (Arora et al., 2001, Britto et al., 2007, OECD, 2010, Niosi et al., 2012b).

The first wave of catch-up countries came with India and their competitive advantage of skilled human capital and English language skills, used in Business Process Outsourcing (BPO). Nowadays, India remains by far the largest exporter of computer and information services, fuelled by the growth of domestic firms.

During the recent economic crisis of 2008-2009, many industries and firms relied on BPO, IT services and software engineering as key measures to reduce costs. India benefited from these trends and therefore, the Indian ICT and Software industries remained strong during the crisis. Figure 1 shows the revenues of the IT sector in India and the percentage change on a rear-on-year basis.

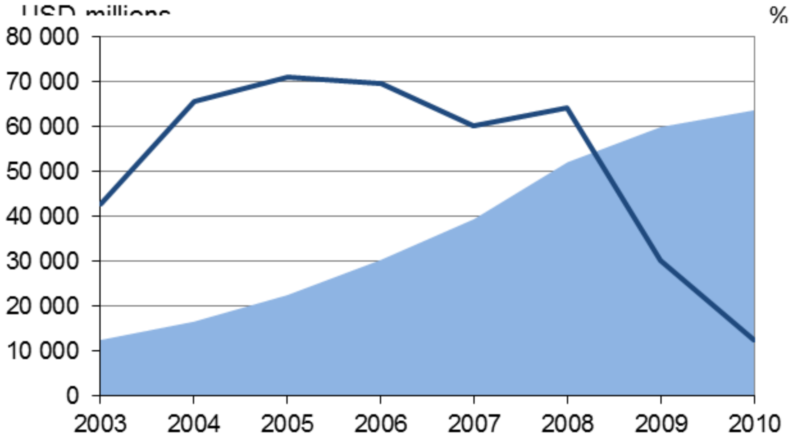

Figure 1. Revenues and growth of the IT sector in India (2003-2010) - USD millions (left scale), year-on-year percentage change (right scale). Source: OECD (2010)

The second wave included China and Philippines. China became a major player by taking advantage of its large domestic market and the Philippines copied India's strategy: expertise on BPO (Niosi et al., 2012b). China is the largest exporter of ICT goods, driven by foreign investment and sourcing arrangements. In 2008 China's ICT exports were only slightly behind the combined exports of the United States, the EU27 (excluding intra-European trade) and Japan.

The third wave includes Brazil and Argentina among others (Malerba and Nelson, 2011, Niosi et al., 2012b). Brazil ranks already in the 11th position of the world's largest markets with a domestic market of US$ 17.3 Billion, which as in the case of China, has been the major driver for its growth (ABES, 2011).

As Asian countries realized, Brazil and other Latin American countries have gained awareness of the importance of KIBS sectors – such as Software – and the service sector in general, in economic development and competitive increase of regions and nations (Miles, 2004, Antonelli, 2000, Tomlimson, 2000).

In the study of the top 250 ICT firms in the world, the employment levels for the Software Sector showed a growth of around 100% between 2000 and 2009 (OECD, 2010). Figure 2 shows the employment trends of the software sector and other ICT sectors in the OECD study.

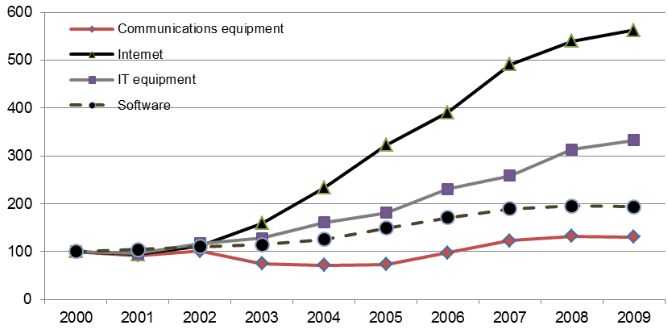

Figure 2. . Employment rates in the top 250 ICT firms - 2000-2009, Index 100=FY2000. Source: (OECD, 2010)

In the same study, there was a clear increase in the period 2000-2009 in terms of revenue per employee, software firms generated on average USD 400.000 per employee, above the ICT average of USD 298.000 per employee (OECD, 2010).

One of the main reasons that explain the high performance level of the Software Sector, in terms of revenue and employment rates, is the high innovative capability embedded on its firms. In this sense, the velocity at which scientific research and R&D are transformed into products ready for the market is higher than other sectors due to the unneeded technological adaptation (Jensen et al., 2007).

Accordingly, Lippoldt and Stryszowski (2009) sustain that the software sector is among the most dependent sectors on R&D to generate innovation because R&D costs are comparatively higher than the marginal costs of software production. This might explain why most industry leaders have shown high expenditures on R&D in the last years, mostly by the private sector.

Data on Business Expenditure R&D (BERD) from the OECD shows that the largest accounts of R&D expenditures by the private sector in absolute numbers are from the United States, Israel, Japan and Germany, with only a few developing countries appearing on the list, like China and India (Lippoldt and Stryszowski, 2009).

Furthermore, in a study conducted by the European Commission (EC), aiming at identifying the R&D performance with 1400 firms in 22 sectors, the software sector appeared in the top five sectors, with an R&D intensity (as % of sales) of 9.8% and absolute R&D investment of 26.52 Bi [EUR] (EC, 2007).

However, software production is not only R&D intensive. It involves the use of other knowledge and information sources, like human capital training, user-producer interaction as well as the technical possibilities afforded by improved hardware capabilities (acquisition of hardware and other equipment). Only a few regions in the world have national statistics that can serve as proxies to measure the effects of such additional variables, the most known example is the Community Innovation Survey (CIS) from the European Union, which asks firms about their use of other information and knowledge sources than R&D. The Brazilian PINTEC survey, followed the guidelines of the CIS, and thus it offers a wide range of indicators that can help to understand the innovative performance of the Brazilian Software Sector.

In this sense, the next Section, will introduce and discuss the main elements of the Brazilian Software Sector, by focusing on their structural characteristics and innovative activities and performance.

1.5 INNOVATION IN THE BRAZILIAN SOFTWARE SECTOR

Over the last decades, the Brazilian software sector has developed constantly, becoming one of the world's major players.

1.5.1 Structural characteristics of the Brazilian Software Sector

From a historical perspective, the Brazilian software sector had two major periods, the first one (1970s and 1980s) was led by government protectionism and market reserve regulation which caused to a large extent a 'copycat' behavior between producers of national software trying to imitate international software unavailable locally at the time and also delayed the learning curve of local users. the domestic industry was growing in insulation from the dynamic technological change that was taking place in the international IT industry during the 1980s becoming gradually uncompetitive, moreover, an important shortcoming was the inadequate and insufficient learning by local IT firms (Cassiolato et al., 2007).

Beginning in the 1990s the second period was characterized by a market opening and by fiscal incentives to R&D activities. The new regulation promised fiscal benefits to firms that would invest at least 5% of their sales in R&D activities, 2% of which would have to be in research collaboration with universities and research institutes (Britto et al., 2007). Between the period 1991 and 2001, the share of Software Sector in the country's GDP had evolved from 0.27% to 0.71% (Britto and Stallivieri, 2010).

This helped in linking the software sector with several large manufacturing sectors in the country, which were in the need of technological solutions to improve their operations. Another important difference with respect to other global players is the public policy approach – incentives from sectoral and national policy – taken in Brazil, which had focused on improving the competencies of its human capital and in developing expert knowledge on the sectors they helped in developing

Firms, revenues and labor force

According to Roselino (2006), for year 2001, software activities in Brazil corresponded already to the seventh largest world market, in terms of domestic sales, reaching up to 7.7 Bi [USD] and a labor force of 160.000 people. For 2002, the same author estimated a total of 188.233 people employed and a total of 10.457 firms.

Large firms in the sector, during the period 2002-2004 decreased in quantity, from 33 to only 20, while total revenue went up, from 128 Bi [USD] for year 2002 to 168 Bi [USD], for year 2004, with an increase of the average revenue per firm from 38.9 Mi [USD] to 84.0 Mi [USD] (Britto and Stallivieri, 2010).

Data from the International Data Group (IDC) indicated that for year 2006 the total sales of the software sector was around 9.09 Bi [USD], reaching a share of 0.85% of Brazilian GDP (Britto and Stallivieri, 2010). From the same data, a total of 7.818 firms would be recognized as software and related service firms, out of which, 1.894 firms would be software developing firms, 4.197 firms would be dedicated to distribution and commercialization of software products and 1.727 firms dedicated to software-related services. From the software developing firms, 99.25% of them were Small and Mediumsized firms (SMEs), between 1-500 employees and the other 0.75%, large firms (more than 500 employees).

In terms of market segmentation, for 2006, out of the 9.09 Bi [USD] in total revenue, a 36% belonged to software products *per se* and 64% to software services (See Table 1).

Table 1. Market segmentation by product type (2006)

Type	Volume (USD Millions)	Share (%)	Change 2006/2005 (%)
Packaged Software	477	14.6	20.0
Custom Software	760	23.3	14.6
Semi-custom software	2 023	62.1	36.1
Sub-total Software	3 260	100.0	19.8
Sub-total Services	5 830	--	24.2
Total - Software and Services	**9 090**	**--**	**22.6**

Source: Britto and Stallivieri (2010)

Also, in Table 1, the software product sub-segments showed a dominance of semi-custom software of software products (62.1%), followed by a 23.3% share of custom software and 14.6% of packaged software, totaling 3.26 Bi [USD].

On the other hand, Table 2 shows the Brazilian market segmentation for year 2006 by product origin.

Table 2. Market segmentation by product origin (2006)

Type	Volume (USD Millions)	Share (%)	Change 2006/2005 (%)
Developed in a foreign country	2 200	67.5	20.0
Custom Software	760	23.3	14.6
Standard - domestic production	250	7.7	36.1
Export - domestic production	50	1.5	
Sub-total Software	3 260	100.0	19.8
Services - domestic market	5 635	96.7	23.9
Services - exports	195	3.3	37.3
Sub-total Services	5 830	100.0	24.2
Total - Software and Services	**9 090**	**--**	**22.6**

Source: Britto and Stallivieri (2010)

According to Table 2, 67.5% of total sales corresponded to software developed abroad, whether as 23.3% was custom software, only 7.7% share of standard software from domestic production and finally, 1.5% from exports of domestic production. Table 2 also shows a strikingly 96.7% of software services revenue came from the domestic market and only 3.3% from service exports.

For year 2007, Diegues and Roselino (2011) estimated the size of the software sector labor force in 274.752 people.

The 2009 Annual Research on Services (PAS-2009) Report estimated that the Brazilian IT sector had produced a net revenue of 46.86 Bi [R$] approximately 26 Bi [USD], out of which, 21.44 Bi [R$] corresponded to custom and packaged software development (IBGE, 2009). Accordingly, the PAS-2009 reported a total of 362.148 people employed by 47.642 firms in the IT sector (IBGE, 2009).

For the year 2010, more than 8.000 firms were identified as pertaining to the software and services sector, 2.117 of which were declared as software developers and producers. In terms of firm size, 87% (1842 firms) were considered SMEs and only a 13% of those were Large Firms (ABES, 2011).

For the year 2011, Brazil reported a domestic software market of 17.3 Bi [USD], an export market of 1.7 Bi [USD] and a global market share of 1.9%, above other traditional catch-up countries such as India, which clearly illustrates the dominance of the domestic market as the main market in the Brazilian software sector (ABES, 2011, Britto and Stallivieri, 2010, Roselino, 2006).

On the other hand, as the main reasons for the increase of software firms in the country, Britto and Stallivieri (2010) accounted for three mechanisms. First, most Brazilian software firms were created as spin-offs from other firms, usually by former employees, which envisioned market opportunities; in a small scale, spin-offs coming from Academia (Universities and Higher Education Institutions in general). Second, the appearing of a growing number of start-ups, created by people with, usually, technical and engineering backgrounds and their relationship with a growing number of business incubators across the country (ParqTec Alfa in Florianopolis, TecnoPUC in Porto Alegre to name a few). And third, the existence of large governmental companies, like the Federal Service for Data Processing – SERPRO, which are generally specialized in handling large amounts of Federal data.

It is also worth noting that in the last years the sector has tended to concentrate, which has forced domestic firms to be more competitive and also to engage with foreign software firms operating in the Brazilian market, in order to maintain their market shares (Britto and Stallivieri, 2010). In this sense, a more detailed analysis on the effects of foreign firms might help in unveiling additional structural relationships in the Brazilian software sector.

Foreign versus Domestic firms

The Brazilian software market is mainly occupied by Multinationals (MNCs), which have a significant presence in several horizontal segments in the industry. Thus, leaving domestic firms to act on vertical segments, like the Banking System for example (Britto and Stallivieri, 2010). In this sense, domestic firms are mainly concentrated in Enterprise Resource Management (ERP) solutions, like Totvs, whom in the last years acquired some other ERP firms like Datasul and RM Sistemas.

Roselino (2006) collected data from 2002 in relation to the share of domestic and foreign firms in the sector: from a total of 10.447, 10.347 firms were domestic (99%) and only 110 were foreign firms (1%). However, in terms of revenue, from a total of 15.7 Bi [R$], domestic firms had a share of 10.13 Bi [R$] (64.6%) and foreign firms had 5.57 Bi [R$] (35.4%).

Relative differences however are larger when average values are compared, namely, average workforce and average revenue per employee. Domestic firms had an average of 16 people employed and an average revenue of 979.914 [R$] per employee while foreign firms an average of 199 employees and an average revenue of 50.71Mi [R$] per employee (Roselino, 2006).

In this line, Tigre and Marques (2007) identified the ten largest software firms in the packaged software and in the related services segments. Table 3 shows these results for the packaged software Brazilian market, it is worth noting that data on Table 3 was collected for year 2005, since then, the market has had changes like the acquisition of Datasul by Microsiga (which is currently known as Totvs).

Table 3. Ten largest firms on the packaged software segment - 2005.

Firm	Country of Origin	Revenue with software (x1000USD) (a)	Total Revenue (x1000USD) (b)	(a)/(b)	Workforce (c)	(b)/(c)
Microsoft	United States	519 582	525 893	98.8%	400	1 315
IBM Brasil	United States	273 830	1 722 200	15.9%	12 000	144
Oracle	United States	221 048	317 142	69.7%	800	396
Microsiga	Brazil	136 383	161 782	84.3%	1 779	91
SAP	Germany	122 746	167 001	73.5%	350	477
Computer Associates	United States	99 368	112 164	88.6%	300	374
Datasul	Brazil	80 617	123 645	65.2%	2 500	49
Consist	Brazil	79 081	154 456	51.2%	600	257
Symantec	United States	56 079	69 490	80.7%	80	869
Hewlett-Packard	United States	42 898	1 099 960	3.9%	1 300	846

Source: Tigre and Marques (2007)

According to Table 3, only three firms were from Brazilian origin in 2005: Microsiga, Datasul and Consist. More recently, Microsiga became Totvs, and acquired Datasul. Consist Software Solutions, on the other hand, began an agreement with IBM to offer new embedded software from IBM to its customers – from the Banking, Telecom, Utilities, Government and Health sectors.

Another interesting result from Table 3 is that in relative terms, Microsiga and Datasul were the two firms in the list with the worst revenue per employee, 90.940 and 49.458 [USD] per employee, respectively, which suggests that foreign firms might be more efficient than domestic ones.

Moreover, Tigre and Marques (2007) identified only 14 domestic firms within the 50 largest software product firms in the country. Domestic firms’ total revenue was approximately one fourth of foreign ones (Table 4).

Table 4. Selected variables for the 50 largest software product firms - 2005

	Domestic	**Foreign**
Firms (a)	14	36
Total Revenue (x1000 USD) (b)	1 484 163	6 498 011
Average Revenue (b)/(a)	106 012	180 500
Revenue with packaged software (c)	464 445	1 783 710
Average revenue with software product (c)/(a)	33 175	49 548
(c) / (b) %	31.3	27.5

Source: Tigre and Marques (2007)

As shown on Table 4, foreign firms had a relative better performance than domestic ones, especially when comparing the average revenue per firm and the average revenue with packaged software. In addition, the 50 largest firms in product software accounted for 79% of the total product software market in Brazil, which reached 2.8 Bi [USD] for year 2005.

On the other hand, Table 5 shows the ten largest firms in the software services segment. Data was collected for year 2005 and since then, some changes had been observed, like the acquisition of EDS (Electronic Data Systems Inc.) by Hewlett-Packard, becoming HP Enterprise Services; and CPM Braxis became the first Brazilian Software Firm in being awarded with a Capability Maturity Model Integration for Development (CMMI-DEV) – Level 5.

Table 5. Ten largest firms on software services segment - 2005. Source: Tigre and Marques (2007)

Firm	Country of Origin	Revenue with software services (x1000USD) (a)	Total Revenue (x1000USD) (b)	(a)/(b)	Workforce (c)	(b)/(c)
IBM Brasil	United States	799 101	1 722 200	46.4%	12 000	144
EDS	United States	500 602	500 602	100.0%	6 800	74
Unisys	United States	248 765	376 917	66.0%	2 100	179
Accenture	United States	227 619	281 012	81.0%	5 000	56
Hewlett-Packard	United States	206 792	1 099 960	18.8%	1 300	846
Politec	Brazil	195 705	195 705	100.0%	6 500	30
Xerox	United States	174 185	688 479	25.3%	1 600	430
Diebold-Procomp	United States	173 998	381 574	45.6%	2 500	153
CPM Braxis	Brazil	168 607	255 078	66.1%	2 600	98
Cobra	Brazil	160 083	253 697	63.1%	6 800	37

Source: Tigre and Marques (2007)

Table 5 shows that the two less efficient firms in the list, in terms of revenue per employee were domestic ones, Politec and Cobra, with values of 30.108 and 37.308 [USD] per employee respectively.

Also, Tigre and Marques (2007) compared the relative performance of the 50 largest software service firms. In their study, 22 firms were identified as domestic ones and 28 as foreigners. Differently than the 50 largest software products firms, in the software service segment, at first hand there is a more balanced distribution, even when revenues are compared, as shown on Table 6.

Table 6. Selected variables for the 50 largest software service firms - 2005

	Domestic	Foreign
Firms (a)	22	28
Total Revenue (x1000 USD) (b)	2 925 734	11 277 492
Average Revenue (b)/(a)	132 988	402 768
Revenue with software services (c)	1 793 959	3 590 117
Average revenue with software services (c)/(a)	81 544	128 218
(c) / (b) %	61.3	31.8

Source: Tigre and Marques (2007)

According to Table 6, revenue with software services in domestic firms was approximately one half of foreign firms' revenue. As the case of software products, in the software services segment, foreign firms showed a better performance as well, in both, the average revenue and in the average revenue with software services. In addition, the 50 largest firms in this segment responded for 63.5% of the total software service market in Brazil, which reached 8.5 Bi [USD] in 2005 (Tigre and Marques, 2007).

On the other hand, another aspect that must be taken into account, in order to understand the Software Sector in Brazil, is the purchasing power of the public sector.

Government and public sector purchasing power

The Brazilian public sector is one of the most important customers for software and related IT services. Roselino (2006) collected data related with the purchasing activities of the Federal Government for year 2002 and revealed that 62% of total government expenditures (727 Mi [R$]) on software and related services were concentrated in public software enterprises. Domestic private firms accounted for 33% and foreign firms accounted for 5%. Data from the Brazilian Ministry of Planning for year 2011, estimated a total of 51.78 Bi [R$] for Federal government purchases[1]. A total of 1.27 Bi [R$] were spent in Hardware, Software and related equipment.

The dominant share of the public software enterprises implies that domestic private firms do not have enough space to compete against public companies, which are clearly privileged in Federal software purchases. On the other hand, it also implies that foreign firms do not benefit from the Public Sector market, which somehow, increases the chance of domestic private firms to sell their products in this market. In fact, a new Federal regulation gives a margin of 25% preference in price, for purchases of the Public Sector, to domestic IT firms. This means, that a domestic IT product might be up to 25% more expensive than a foreign one, and still win the procurement process.

In addition, the Federal Government has responded to the dominance of United States and other European firms by promoting the

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[1]http://www.comprasnet.gov.br/ajuda/Brasil_Econ%C3%B4mico_Relatorio_Dados_Gerais_Janeiro_a_Dezembro2011.pdf

procurement of open source software, which restricts foreign players and offers relative advantages to domestic firms. This policy has been used by many catching-up countries as well, in order to respond to the dominance of developed countries (Klincewicz and Miyazaki, 2011).

The policies described above are just some examples of recent policies which aim at improving the performance and innovative capability of the Software Sector. In the next section, some additional relevant sectoral policies will be described.

Sectoral Policies in the Brazilian software sector

In 1996, the Association for the Promotion of Brazilian Software Excellence (SOFTEX) was established; SOFTEX is an organization of public interest for the civil society, which is responsible for the Program for Brazilian Software Excellence, the SOFTEX Program.

This program has as objective the development of markets and the sustainable expansion of the Brazilian Industry of Software and IT Services' competitiveness. Within their initiatives, the Programme for the Development of Software Industry and Services National Information Technology (PROSOFT) is highlighted, which was created with help of BNDES aiming to stimulate the competitiveness of the Brazilian software industry and recently renovated until July 2012. The PROSOFT program is divided into three subprograms:

- Prosoft - Company (financing for investments and business plans of domestic companies producing software and related services);
- Prosoft - Marketing (financing for the acquisition in the domestic market, software and related services developed in Brazil); and
- Prosoft - Export (financing the export of software and related services developed in the country, by a process of pre-shipment and post-shipment).

Another important policy, promoted by the Federal Government have been the Sectoral Funds, which were established since late 1990s, meant to finance research, development and innovation projects in key strategic fields or sectors, by using specific funds coming from taxation on natural resources, excise taxes and from the Contribution for Intervention in the Economic Domain (CIDE). Currently, there are 16

Sectoral Funds, one of them is the Sectoral Fund for Information Technology (CT-INFO), which aim is to promote strategic R&D projects in IT in firms within the IT sector.

In 2004, the Industrial, Technological and International Trade Policy (Pitce) included as one of the key strategic sectors, the software sector (BRAZIL, 2003, Roselino, 2006, ABDI, 2011)

1.5.2 Innovative activities in the Brazilian Software Sector

Innovative activities in the Software Sector in Brazil are difficult to assess due the lack of standardized measurements related to what actually is contained within software activities. This represents a challenge for studies related with software activities and especially for innovation in such activities. One option that has proven to be successful when studying other industrial sectors' innovative activities in Brazil is the use of PINTEC data. PINTEC surveys were developed to assess the level of innovative activities in different sectors of the economy (IBGE, 2010, IBGE, 2007), in particular, the edition 2005 accounts for two sub-categories that relate to software activities: *"Software consulting"* and *"Other information technology and services related activities",* with a total sample of 3811 firms. At the same time, the 2008 edition accounts for similar sub-categories: *"Development and licensing of computer programs"* and *"Other information technology services"* with a sample of 2514 firms.

Thus, in this Dissertation is used data from PINTEC, based on the notion that by using a more standardized and validated device, it could help in increasing the confidence of data explaining how innovative activities have taken place in the sector.

The following tables show reorganized data from PINTEC-2005 and PINTEC-2008, highlighting the innovative character of the software sector, when compared with the rest of the industry.

Table 7 shows the main indicators for the Software Sector from PINTEC-2005 and PINTEC-2006.

Table 7. Innovation Rate of industrial and service sectors in Brazil

Innovative Rate		Total (c+d)	Extractive and Manufacturing Industries (c)	Service Sector (d)	Software Sector
2003 to 2005	Total Firms (a)	95 301	91 054	4 246	3 811
	Innovative Firms (b)	32 796	30 378	2 418	2 197
	Innovation Rate (a/b)%	34.4%	33.4%	56.9%	57.6%
2006 to 2008	Total Firms (a)	106 862	100 496	6 366	2 514
	Innovative Firms (b)	41 262	38 299	2 963	1 343
	Innovation Rate (a/b)%	38.6%	38.1%	46.5%	53.4%
Innovation Rate Diff (2008-2005)		4.2%	4.7%	-10.4%	-4.2%

Source: IBGE (2010), IBGE (2007)

The most important aspect of Table 7 is that the Software Sector had shown a better innovative performance than the average of manufacturing and services (in PINTEC the software sector is considered as part of the service sector). Even though the innovation rate decreased slightly between the 2003-2005 and the 2006-2008 periods, it still remained higher than total averages.

Accordingly, Table 8 shows some additional figures related with the expenditures on innovative activities and some performance indicators. In terms of revenue per firm, the software sector showed an increase in 66% between 2005 and 2008. Also, in terms of innovation expenditures as a share of revenue, the sector showed higher numbers in relation to total average of the industry.

Table 8. Revenue per Firm, share of firms with innovation expenditures and share of innovation expenditures by revenue.

Innovative Efforts		Total (e+f)	Extractive and Manufacturing Industries (f)	Service Sector (e)	Software Sector
2005	Total Firms (a)	95 301	91 054	4 246	3 811
	Net Revenue (x1000USD) (b)	575 139 807	525 658 096	49 481 711	11 292 376
	Firms with Innovation Expenditures (c)	21 966	19 951	2 015	1 829
1 USD = 2.36R$	Innovation Expenditures (x1000USD) (d)	17 495 429	14 578 805	2 916 624	668 112
2008	Total Firms (e)	106 862	100 496	6 366	2 514
	Net Revenue (x1000USD) (f)	813 792 292	737 656 942	76 135 349	12 536 786
	Firms with Innovation Expenditures (g)	33 034	30 645	2 390	1 245
1 USD = 2.33R$	Innovation Expenditures (x1000USD) (h)	23 220 438	18 767 151	4 453 287	413 752
Revenue per Firm (x1000USD)	b/a (2005) (i)	6 035	5 773	11 654	2 963
	f/e (2008) (j)	7 615	7 340	11 960	4 987
	(j-i)/i	26.2%	27.1%	2.6%	68.3%
Firms with Innovation Expenditures as share of total firms	c/a (2005) (k)	23.0%	21.9%	47.5%	48.0%
	g/e (2008) (l)	30.9%	30.5%	37.5%	49.5%
	(l-k)	7.9%	8.6%	-9.9%	1.5%
Innovation Expenditures as share of Revenue	d/b (2005) (m)	3.0%	2.8%	5.9%	5.9%
	h/f (2008) (n)	2.9%	2.5%	5.8%	3.3%
	(n-m)	-0.2%	-0.2%	0.0%	-2.6%
Innovation expenditures per Firm (x1000USD)	d/c (2005) (o)	796	731	1 447	365
	h/g (2008) (p)	703	612	1 863	332
	(p-o)/o	-11.7%	-16.2%	28.7%	-9.0%

Source: IBGE (2010), IBGE (2007)

Table 9 shows additional evidence on the rates of product and process innovation. Specifically, the sector shows that the share of firms with product and process innovation is higher than the total manufacturing and service average.

Table 9. Product and Process Innovation - Software Sector and total manufacturing and service

Product and Process Innovation		Total (e+f)	Extractive and Manufacturing Industries (f)	Service Sector (e)	Software Sector
Product Innovation 2005	Total Firms (a)	95 301	91 054	4 246	3 811
	Total Firms with PDI (b)	19 670	17 784	1 886	1 689
	Share of firms with PDI (b/a)	20.6%	19.5%	44.4%	44.3%
Product Innovation 2008	Total Firms (a)	106 862	100 496	6 366	2 514
	Total Firms with PDI (b)	25 365	22 963	2 402	1 168
	Share of firms with PDI (b/a)	23.7%	22.8%	37.7%	46.5%
PDI difference	**(b/a) 2008 - (b/a) 2005**	**3.1%**	**3.3%**	**-6.7%**	**2.1%**
Process Innovation 2005	Total Firms (a)	95 301	91 054	4 246	3 811
	Total Firms with PRI (b)	26 277	24 504	1 773	1 590
	Share of firms with PRI (b/a)	27.6%	26.9%	41.8%	41.7%
Process Innovation 2008	Total Firms (a)	106 862	100 496	6 366	2 514
	Total Firms with PRI (b)	34 255	32 264	1 991	693
	Share of firms with PRI (b/a)	32.1%	32.1%	31.3%	27.6%
PRI difference	**(b/a) 2008 - (b/a) 2005**	**4.5%**	**5.2%**	**-10.5%**	**-14.2%**
P&P Innovation 2005	Total Firms (a)	95 301	91 054	4 246	3 811
	Total Firms with P&P (b)	13 151	11 911	1 240	1 082
	Share of firms with P&P (b/a)	13.8%	13.1%	29.2%	28.4%
P&P Innovation 2008	Total Firms (a)	106 862	100 496	6 366	2 514
	Total Firms with P&P (b)	18 358	16 928	1 430	518
	Share of firms with P&P (b/a)	17.2%	16.8%	22.5%	20.6%
P&P Innovation difference	**(b/a) 2008 - (b/a) 2005**	**3.4%**	**3.8%**	**-6.7%**	**-7.8%**

Source: IBGE (2010), IBGE (2007)

Table 10 shows the summary of innovation rate for 2005 and 2008. In all cases the Software Sector shows high innovation values, in most cases higher than Brazil’s average.

Table 10. Summary of innovation rates for the Software Sector and Total Average of Industry and Services

Innovation Rate (% of innovative firms)	**Brazil**		**Software Sector**	
	2005	2008	2005	2008
Total	**34.4**	**38.6**	**57.6**	**53.4**
Product Innovation	20.6	23.7	44.3	46.5
Process Innovation	27.6	32.1	41.7	27.6
Product and Process	13.8	17.2	28.4	20.6

Source: IBGE (2010), IBGE (2007)

Figure 3 shows the relative importance of several information sources for innovative activities. Specifically, most important information sources are internet (informatized networks) and internal sources such as R&D Department and knowledge from other Departments and customers, as the most important external information source for innovative activities.

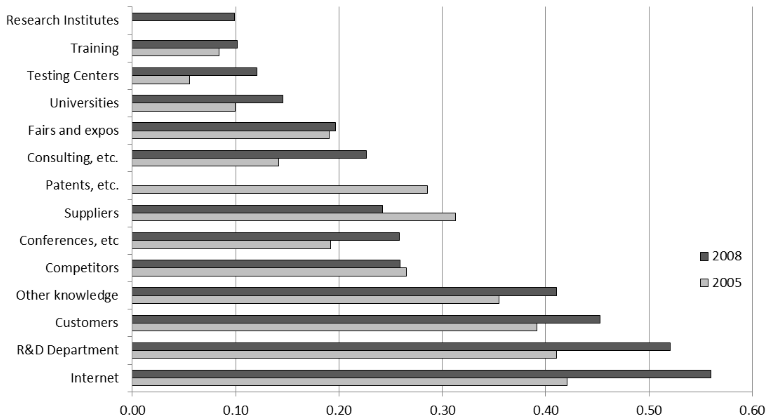

Figure 3. Relative importance of information sources for innovative activities. Source: IBGE (2010), IBGE (2007)

Table 11 shows that the highest expenditures were on in-house R&D activities and in the acquisition of machinery and equipment.

The information summarized in

Table 12 shows a similar pattern than Table 11, that is, most firms had expenditures with in-house R&D and acquisition of machinery and equipment. In addition, high share can also be evidenced in training activities and in the acquisition of software, and to some extent, for 2008, in expenditures with the introduction of innovations into the market.

Table 11. Expenditures on various types of innovative activities.

Innovative activity expenditures in the Software Sector	Code	2005 (1 USD = 2.3607 BRL)*		2008 (1 USD = 2.33BRL)*	
		(x1000USD)	(%)	(x1000USD)	(%)
In-House R&D	IRD	262 736	39.3%	125 763	30.4%
External R&D	ERD	15 702	2.4%	9 782	2.4%
Acquisition of external knowledge	EEK	48 209	7.2%	25 385	6.1%
Acquisition of machinery and equipment	EME	143 098	21.4%	157 452	38.1%
Acquisition of software	ESO	47 724	7.1%	23 295	5.6%
Training	EWT	78 011	11.7%	19 435	4.7%
Introduction of technological innovations into the market	EWC	53 314	8.0%	22 749	5.5%
Industrial design and other technical setups	EOP	19 319	2.9%	29 891	7.2%
Total Innovation Expenditures		**668 112**	**100.0%**	**413 752**	**100.0%**

(*) Data from Banco Central do Brasil

Source: IBGE (2010), IBGE (2007)

Table 12. Share of firms with innovative activities

Share of firms with expenditures on innovative activities (FWEIA) by innovative activity in the Software Sector	2005		2008	
	FWEIA = 1829		FWEIA = 1245	
	# Firms	%	# Firms	%
In-House R&D	1 015	55.5%	328	26.3%
External R&D	80	4.4%	62	5.0%
Acquisition of external knowledge	447	24.4%	342	27.5%
Acquisition of machinery and equipment	1 385	75.7%	836	67.1%
Acquisition of software	883	48.3%	637	51.2%
Training	914	50.0%	665	53.4%
Introduction of technological innovations into the market	567	31.0%	684	54.9%
Industrial design and other technical setups	385	21.0%	387	31.1%

Source: IBGE (2010), IBGE (2007)

On the other hand, data on the main actor responsible for product and process innovations, summarized in Table 13, evidenced that firms themselves were the main responsible for product innovations. For process innovations, the pattern is quite different, in which the main responsible is shared by firms themselves and by other firms and institutes.

Table 13. Main actor responsible for product and process innovations

Main actor responsible for product development within firms which implemented innovations (Software Sector)		Software Sector (2005)		Software Sector (2008)	
		Firms	%	Firms	%
Product	Firm itself	1 425	84.3%	1 057	90.5%
	Other Firm in the group	25	1.5%	14	1.2%
	Firm with other firms or institutes	76	4.5%	71	6.1%
	Other Firms or institutes	164	9.7%	26	2.2%
	Total	1 690	100.0%	1 168	100.0%
Process	Firm itself	542	34.1%	274	39.5%
	Other Firm in the group	19	1.2%	9	1.3%
	Firm with other firms or institutes	93	5.8%	76	11.0%
	Other Firms or institutes	936	58.9%	334	48.2%
	Total	1 590	100.0%	693	100.0%

Source: IBGE (2010), IBGE (2007)

In turn, Table 14 shows that the main funding for both R&D and non-R&D innovative activities came from firms themselves. Although for 2008, the shares of funding from firms decreased slightly for non-R&D and considerably for R&D innovative activities, where public funding showed a higher share.

Table 14. Funding sources for R&D and other innovative activities

Funding Sources share - R&D and other activities (Software Sector)	Code	Software Sector (2005)		Software Sector (2008)	
		R&D	Others	R&D	Others
Own Funding (a)	POF	95.0%	95%	63.0%	82%
Third-party funding - private (c)	IPR	4%	3%	3%	15%
Third-party funding - public (d)	IPU	1%	2%	34%	3%
Total (a+b+c)		**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: IBGE (2010), IBGE (2007)

Complementing previous analysis, Table 15 shows that the share of firms with expenditures on in-house R&D activities, the software sector shows higher relative values for 2005 and 2008.

In terms of average size of R&D Departments, in terms of personnel, the values for the software sector are relatively similar to the rest of the industry (manufacturing and services).

Table 15. Personnel employed on in-house R&D activities

People employed for in-house R&D (Software Sector)	2005		2008	
	All Industry	Software Sector	All Industry	Software Sector
Firms (Total) (a)	95 301	3 811	106 862	2 514
Firms with expenditures in-house R&D (b)	6 168	1 015	4 754	328
People employed (Total) (c)	6 409 876	224 658	7 530 636	201 185
People employed (in-house R&D) (d=e+f+g)	83 944	12 095	73 279	3 367
People with Graduate degree (e)	11 283	1 100	10 292	335
People with Undergraduate degree (f)	38 071	8 306	35 051	2 344
People with other education (g)	34 590	2 689	27 936	688
In-house R&D rate - b/a (%)	**6.5%**	**26.6%**	**4.4%**	**13.0%**
Average size of in-house R&D depts - (d/b)	**13. 6**	**11. 9**	**15. 4**	**10. 3**
Share of people with grad degree (e/d)	**13.4%**	**9.1%**	**14.0%**	**9.9%**
Share of people with undergrad degree (f/d)	**45.4%**	**68.7%**	**47.8%**	**69.6%**
Share of people with other ed (g/d)	**41.2%**	**22.2%**	**38.1%**	**20.4%**
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: IBGE (2010), IBGE (2007)

Finally, data on Table 16 evidences different types of impacts on firms, due to innovative activities, highlighting the impacts on product quality, product portfolio and market shares.

Table 16. Importance of innovative activities by type of impact

Impacts of innovations (high) of innovative firms - Software Sector	(2003-2005)		(2006-2008)	
	Firms	Share of High (%)	Firms	Share of High (%)
Product quality improvement	1 297	59.0%	926	69.0%
Increase in product portfolio	766	34.9%	602	44.8%
Maintenance of market share	1 047	47.7%	776	57.8%
Increase in market share	683	31.1%	592	44.1%
New markets	557	25.4%	477	35.5%
Increase in production capacity	807	36.7%	576	42.9%
Increase in production flexibility	608	27.7%	516	38.4%
Decrease in production costs	479	21.8%	140	10.4%
Decrease in working costs	408	18.6%	-	-
Decrease in raw material	47	2.1%	-	-
Decrease in energy consumption	32	1.5%	-	-
Decrease in water consumption	-	-	-	-
Decrease of impacts on occupational health	42	1.9%	200	14.9%
Decrease of impacts on the environment	-	-	60	4.5%
Increase in the control of occupational health issues	-	-	160	11.9%
Norms and regulations	305	13.9%	311	23.2%
Total	**2 197**		**1 343**	

Source: IBGE (2010), IBGE (2007)

1.6 Conclusions

This appendix has described, to a larger extent, the main aspects of the Software Sector in Brazil. In this sense, it started out by describing some general issues related with software activities, such as the measurement difficulties of software activities, and the nature of software (intangible, product, service and new trends).

Then, an overview of the software sector from a global perspective was presented. In this section, the importance of the sector for global economies was shown, highlighting that knowledge-intensive services (KIBS) have shown good performance, even throughout the past global economic crises.

Afterwards, the Appendix presented the main characteristics of the Software Sector in Brazil, by describing the structure of the sector since the 1980s and some of their main general numbers, such as revenues, personnel employed and number of firms. In the second part, data from PINTEC was used to analyze the main characteristics of innovative activities in the sector and compared to the whole industry averages (manufacturing and service sectors).

Some main conclusions related with the innovative activities in the Software Sector are that it is highly intensive, when compared with manufacturing and service sectors' averages. Also, most innovative activities were identified as in-house R&D and acquisitions of several equipment, machines and software. Most information sources were characterized as the R&D Department and other internal Departments, customers – as external sources, and internet. Most funding of innovative activities (R&D and non-R&D) comes from firm's reinvestments, followed by a recent increase of public funding. Average size of R&D Departments is relatively similar with the total industry average and finally, the impacts identified by firms as outcome of innovative activities were mainly on product quality, product portfolio and market share.

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