Knowledge, Dynamic Capabilities and Family Inertia in Family Firms: A Computational Approach

Francesco Chirico
University of Lugano (USI)
Laboratory of System Modelling (LSM)
Institute of Management
Via G. Buffi 13, 6900 Lugano, Switzerland
Tel: +41586664548
Fax: +41586664647
francesco.chirico@lu.unisi.ch

ABSTRACT

The present research sets out through computer simulations in system dynamics the positive dynamic interconnections between knowledge, capabilities, dynamic capabilities, entrepreneurial performance and trans-generational value in family business.

Interesting results and new insights emerge introducing family inertia in the model (as a function of paternalism) which influences the creation of capabilities and dynamic capabilities negatively, with some exceptions. We conclude that although a paternalistic behaviour can be positive in guiding and training offspring at the beginning of the activity, it may become less crucial if it persists over time preventing change even when it is needed. Family firms should be able to understand the long-term effects and results of actual events, decisions and behaviours, and, at the same time, prevent their negative consequences.

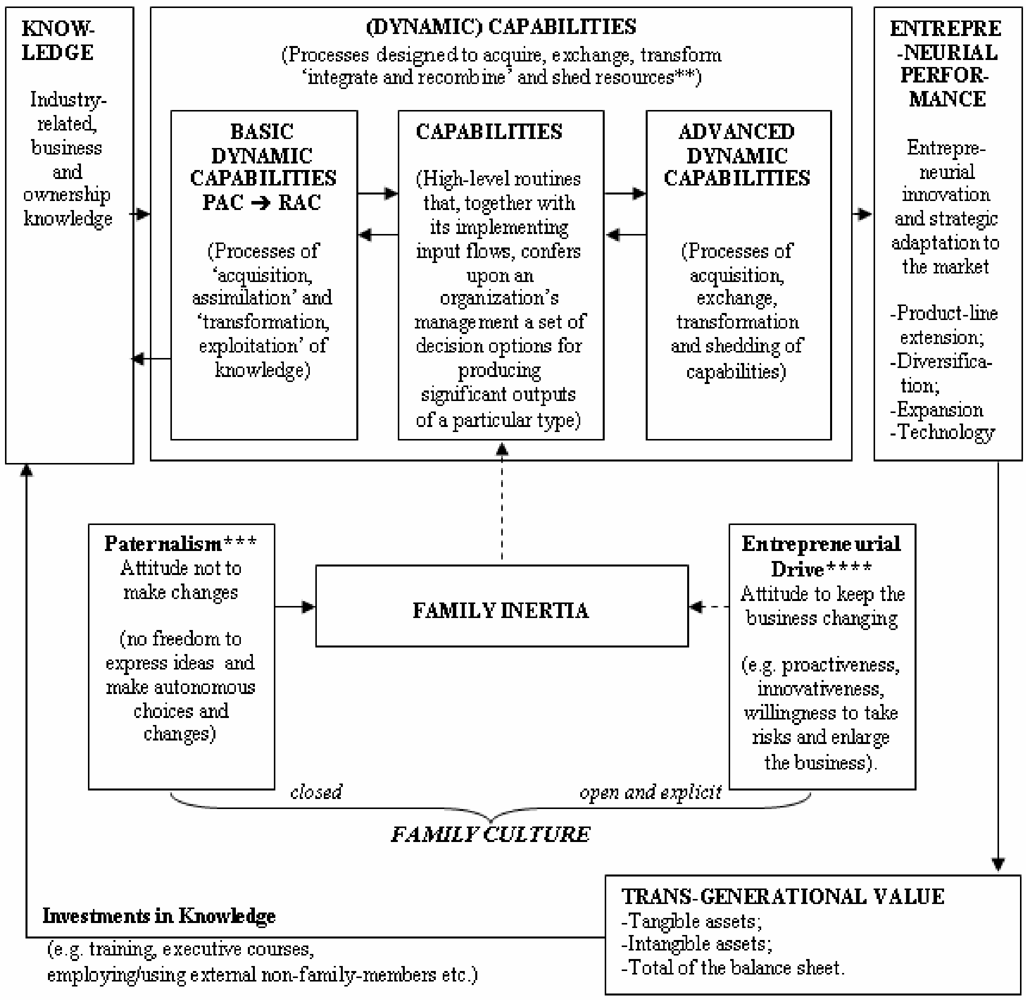
Keywords: simulation modelling, system dynamics, family business, family inertia, paternalism, knowledge, dynamic capabilities, trans-generational value.

Acknowledgments: My personal thanks to Prof Erik Larsen and Prof Gianluca Colombo for helping me in this research. I gratefully acknowledge financial support from the Finnish Ministry of Trade and Industry and from the European Union.

INTRODUCTION

Chirico (2006b) made a detailed examination of the complex dynamic process through which dynamic capabilities are generated by knowledge and generate entrepreneurial performance, allowing a family firm to compete in situations of rapid change and create value over time. Part of this value may be reinvested in the family firm for the creation of new knowledge (e.g. training courses).
For the sake of this argument, dynamic capabilities were seen as a double concept: basic and advanced dynamic capabilities. In addition, family inertia (FI) was considered to be a factor preventing the creation of dynamic capabilities. FI depends on the family-business culture, where paternalism and entrepreneurial drive influence FI positively and negatively, respectively (see figure 1). The research was based on the review of the literature and four in-depth case studies analysed through interviews.

Figure 1: Dynamic model: from knowledge to trans-generational value creation*



Source: Adapted from Chirico (2006b, figure 2)
(*) ____: positive relation; ------: negative relation.
(**) Resources are here interpreted as knowledge and capabilities.
(***) Paternalism influences family inertia positively and family inertia influences (dynamic) capabilities negatively. Consequently, paternalism influences (dynamic) capabilities negatively.
(****) Entrepreneurial drive influences family inertia negatively and family inertia influences (dynamic) capabilities negatively. Consequently, entrepreneurial drive influences (dynamic) capabilities positively.

The theoretical framework (dynamic capabilities, from knowledge to trans-generational value and the family inertia problem) behind the dynamic model in figure 1 has been analysed by Chirico (2006b).
Table 1 provides a list of all the variables studied.

The present research aims at exploring, extending and testing the model above and its dynamic implications through computer simulations in system dynamics, looking for new *insights.*

First, we present the system dynamics methodology which explains what system dynamics is and why it is useful to use it in this study. Then, we analyse the model structure from the feedback loops to the dynamic models, followed by the results and new insights of the research. In this section, we examine four different scenarios describing the evolution of paternalism over three generations (90 years), and their consequent effects on the model as a whole. Finally, we present the discussion and conclusions.

Table 1: list of the variables

KNOWLEDGE. Chirico (2006a) refers to knowledge as “pure knowledge and skill which family and non-family members working in the family firm have gained and developed through education and experience (industry-related knowledge, business knowledge, ownership knowledge)”.

DYNAMIC CAPABILITIES. Dynamic capabilities are defined as processes embedded in firms designed to acquire, exchange and transform internal and external knowledge and capabilities[1] in new and distinctive ways and, at times, shed them to build and sustain entrepreneurial performance in environments of rapid change (Teece et al., 1997; Eisenhardt and Martin, 2000). Absorptive capacity is itself a dynamic capability (Zhara and George, 2002). Dynamic capabilities encompass:

- BASIC DYNAMIC CAPABILITIES (BDC) is absorptive capacity. The first dimension of BDC is named *Potential Absorptive Capacity* (PAC) which is the capacity of acquiring and assimilating external knowledge. Acquisition capability means “the ability to identify and acquire externally generated knowledge”; assimilation capability means “the ability to analyze, process, interpret and understand knowledge acquired from external sources”. The second dimension of BDC is named *Realized Absorptive Capacity* (RAC) which is the capacity to transform and exploit the knowledge that has been absorbed. Transformation capability means the ability to “develop and refine the routines that facilitate combining existing knowledge and the newly acquired and assimilated knowledge”; exploitation capability means “the ability to refine, extend, and leverage existing competencies or to create new ones by incorporating acquired and transformed knowledge into its operations” (Zahra and George, 2002);
- ADVANCED DYNAMIC CAPABILITIES defined as processes (e.g. product development process) embedded in firms designed to acquire, exchange and transform capabilities in new and distinctive ways and, at times, shed them to build and sustain entrepreneurial performance in environments of rapid change.

ENTREPRENEURIAL PERFORMANCE. It is defined as a new and innovative form of competitive advantage (Teece et al., 1997) given by entrepreneurial innovation and strategic adaptation to the market (Barney, 1991; Zahra and George, 2002).

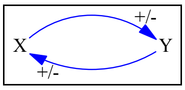
TRANS-GENERATIONAL VALUE CREATION IN FAMILY BUSINESS. It is accumulated through continuous creation of business wealth and is measured by focusing on the net asset value of the tangible assets, the estimated amount of intangible resources (goodwill) and the total of the balance sheet of the family firm.

FAMILY INERTIA. It is defined as the tendency of family firms to resist change even when it is needed to match the requirements of a changing environment. It is a function of paternalism and entrepreneurial drive in family business where paternalism and entrepreneurial drive influence family inertia positively and negatively, respectively. The ideology of *paternalism* is protective and dominating in a fatherly way with a strong attitude to preserve family firm’s traditions and not to make changes (Fotion, 1979; Johannisson et al., 2000; Johannisson, 2002; Koiranen, 2003). *Entrepreneurial drive* is the attitude to keep business changing through initiative and innovation (Johannisson, 2002; Habbershon and Pistrui, 2002; Koiranen, 2003).

[1] According to Winter (2000: 991), “an organizational CAPABILITY is a high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization’s management a set of decision options for producing significant outputs of a particular type”.

METHOD: A SYSTEM DYNAMICS APPROACH

System dynamics is an approach to modelling the dynamics of complex feedback systems through formal computer simulations. Feedback is a core concept in system dynamics. It refers to the situation of X affecting Y and Y, in turn, affecting X through a chain of causes and effects. Causal loop diagrams are used to represent the feedbacks of a system, that is, the way a system is connected by positive (*self-reinforcing*) and negative (*self-balancing or self-correcting*) feedback loops (Forrester, 1961, 1968; Sterman, 2000):



For more details, see Appendix D. Feedback loops are useful to capture and communicate mental models but they have many limitations. For instance, they do not take into consideration the stocks and flows of the system (Sterman, 2000).

System dynamics is based on the *Principle of Accumulation*. It states that all dynamic behaviours in the world occur when *flows* accumulate in *stocks* (figure 2). Stocks and flows are the basic building blocks of a system dynamics model which allow us to analyse the feedback loops of the system[2] (Forrester, 1961, 1968; Morecroft, 1982, 1983; Morecroft and Sterman, 1992; Sterman, 2000; Mollona, 2000; Lomi and Larsen, 2001).

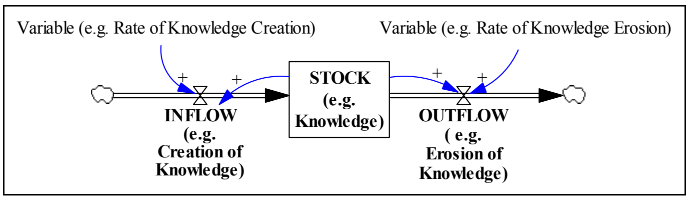
A *stock* is an entity which is accumulated over time by inflows and depleted by outflows. It accumulates past events characterising the state of the system. A Stock typically has a certain value at each moment of time (e.g. knowledge). Mathematically, a stock (S) can be seen as an integration (accumulation) of the difference between inflow and outflow (F) in the long term:

$$St = \int_{t0}^{t} \left[Inflow(t) - Outflow(t) \right] dt + S(t0)$$

A *flow* changes a stock over time by inflows (e.g. creation of knowledge) and outflows (e.g. erosion of knowledge). It is typically measured over a certain interval of time. Mathematically, a flow (F) can be seen as the derivative of the stock (S) with respect to the time (t) that is its net rate of change:

$$F = inflow - outflow; \;\; F = \frac{dS}{dt}$$

Figure 2: Stocks and Flows[3]



[2] A series of constant and auxiliary variables are also needed to simulate the model of the system.

[3] Sterman (2000:192) explains that "- Stocks are represented by rectangles; - Inflows by a pipe pointing into (adding to) the stock; - Outflows by a pipe pointing out (subtracting from) the stock; - Valves (at the center of flows) control the flows; - Clouds (at the extremities) represent the sources and sinks for the flows (boundaries)".

Stocks are the source of delays. A *delay* is the amount of time by which an event is retarded. It is the time between the instant at which a given event occurs and the instant at which a related aspect of that event occurs (e.g. time between the creation and absorption of knowledge). Delays are responsible for generating effects which are very often nonlinear and counter-intuitive in the real world (Sterman, 2000).

The system dynamics methodology follows three steps:
- taking into consideration a *System*[4];
- *Model*[5] the System;
- *Simulate*[6] the Model.

Simulation models are generally based on theories treated as mental models which must be translated into computer models. System dynamics is a powerful method to build a shared understanding and gain useful *insights* into situations of dynamic complexity created by interdependencies, feedbacks, time delays and nonlinearities (Sterman, 1992; Van Ackere et al., 1993; Sterman, 2000).

Conducting empirical researches and, then, formalising and testing them through simulation in system dynamics can be useful to confirm or bring about radical changes in basic assumptions. Propositions and hypothesis can be interlinked and new insights may emerge for further research (Morecroft and Sterman, 1992; Senge and Sterman, 1992; Oreskes et. al, 1994; Sterman, 2000; Lomi and Larsen, 1999, 2001).

Larsen and Lomi (1999: 412) report what has been said by Sutton and Straw (1995): "Hypothesis can be part of a well crafted theoretical argument…but hypothesis do not (and should not) contain logical arguments about why empirical relationships are expected to occur".
For this reason, Larsen and Lomi (1999: 412) view "computer simulation as useful as systematic empirical research for extending and testing organizational theories".
Lomi and Larsen (2001: 11) posit that "computational and simulation models of organizations differ from other kinds of models like empirical models, only in terms of the constraints that define the specific language being used". Masuch's view (1995) is that the validity of simulation models presents the same problems of any other kind of empirical model. Oreskes et al., (1994) and Sterman (2000) agree that validation and verification of numerical and simulation models are impossible but this is not limited to computer models but to any theory and research which relies on simplifications of the real world and assumptions.

This research relies on computer simulation models through system dynamics not as an alternative to empirical research but as a way of exploring, extending and testing the findings, thoughts and the dynamic implications of the complex dynamic feedback

---

[4] A system exists and operates in time and space.
[5] A model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system.
[6] A simulation is the iteration of a model in such a way that it operates on time or space to compress it, thus enabling one to perceive the interactions that would not otherwise be apparent because of their separation in time or space.

structure of figure 1 (see Hanneman et al., 1995; Senge and Stermann, 1992; Larsen and Lomi, 1999; Bothner and White, 2001). System dynamics allows us to explore and understand the future effects and results of actual events and decisions taking into account temporal delays. The existence of delays and feedback loops in the model in figure 1 makes system dynamics once more useful to represent the interdependent relations among variables studied over generations in family business.
Several simulations will be run and interesting results and new *insights* will emerge (see figure 7, figure 10 and Appendix B).

Hanneman et al., (1995: 3) posit that "we do not really know what a theory is saying about the world until we have experimented with it as a dynamic model" and Bothner and White (2001: 206) point out that "simulation models are always formulated as mechanisms for simplifying the moving parts of a social process down to it core features…and yield surprising *insights* for further exploration".

Experimental design
To make simulations, it was necessary to assign numerical values to all parameters, initial values to stocks and proper shapes to graphic functions according to the literature and case studies analysed by Chirico (2006b). Assumptions were also made when useful information could not be taken from the research mentioned above. Numerical values were not chosen randomly but have always been calibrated to be consistent across the model (Larsen and Lomi, 1999, 2002; Lomi et al., 2005).
Sterman (1992: 10) points out that "the skilled modeller uses all available information sources to specify the relationships in the model (numerical data, interviews, direct observation and other techniques)".
To make simulations simpler, graphic functions were built through linear relations.
This kind of representation through "graphic converters" (graphic functions), which specify the functional relationship between two variables, makes very simple to test a dynamic model and analyse possible implications derived by variations in the graphic function(s) (Larsen and Lomi, 1999, 2002; Lomi et al., 2005).
More details in Appendices A, B and C.

The software used for the computer simulation is Vensim PLE for Windows, Version 5.4d. Table 2 indicates the settings of the software.

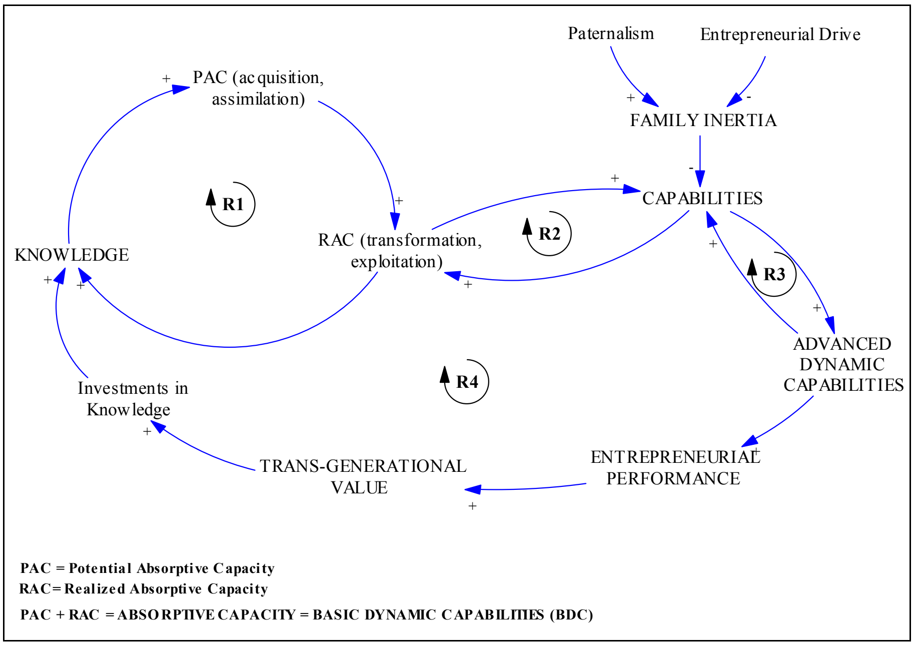
Table 2: Settings of the software Vensim PLE, 5.4d.

INITIAL TIME: 0;
FINAL TIME: 90 (the software Vensim makes the simulation over three generations of a generic family firm in which each generation lasts 30 years);
TIME STEP: 0.125 (results of simulation are saved every 1.5 months. This way, numerical integration errors are kept very small);
UNITS FOR TIME: 1 year (the software Vensim simulates the model every year).

MODEL STRUCTURE: FROM FEEDBACK LOOPS TO DYNAMIC MODELS

The feedback loop representation of the dynamic model for the trans-generational value creation in family business is plotted in figure 3. The reciprocal relations between key variables emerge with four reinforcing loops (**R**). The first feedback loop (R1) specifies the relation between knowledge and basic dynamic capabilities (PAC and RAC). The second one (R2) identifies the relation between RAC and capabilities. The third feedback loop (R3) shows the relation between capabilities and advanced dynamic capabilities. It is also underlined the negative effect of family inertia on the creation of new capabilities. Finally, the fourth feedback loop (R4) indicates the entire complex dynamic process from knowledge to trans-generational value creation, and back to knowledge through investments in knowledge (Chirico, 2006b).

Figure 3: Feedback loops*



Erik Larsen, 2006; Personal Communication
Source: Adapted from Chirico (2006b, figure 2)

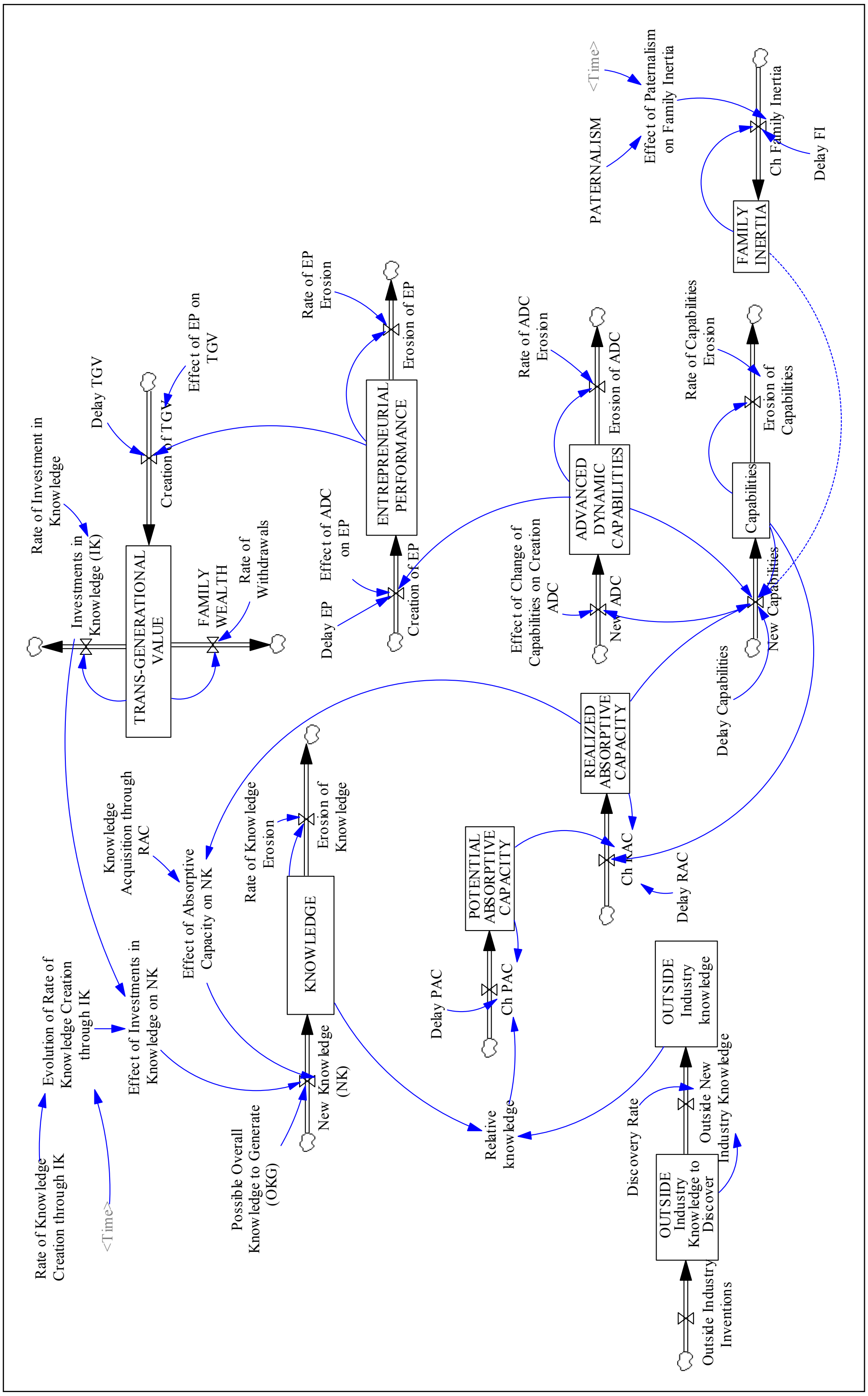
(*) The "+" means that the two variables move in the same direction, all other things being equal.
The "-" means that the two variables move in opposite directions, all other things being equal.

To understand all dynamic implications of the model, feedback loops will be translated into a system of equations rather than a series of different propositions. Variables will be represented as stocks/flows and measured in dimensionless units (see Sastry, 1997; Larsen and Lomi, 1999) (see figure 4).

Computer simulations will give evidence of the positive dynamic interconnections between variables studied and the negative effect of family inertia on the model as a whole. After this general overview, it is now possible to represent the micro-structure of the model, trying to develop the same strategy used by Larsen and Lomi (2002: 279): "Our strategy is to keep notation as much as possible intuitive with the development of a minimal amount of formalism".

Graphic details of the micro-structure of the dynamic model are plotted in figure 4.

Figure 4: Dynamic model in system dynamics*, **



Erik Larsen, Personal Communication

(*) To make the model simpler, entrepreneurial drive is not included in the simulation model.
(**) "___" means that the two variables move in the same direction, all other things being equal.
"----" means that the two variables move in opposite directions, all other things being equal.

Representing knowledge (K). Knowledge is represented as a stock (accumulator[7]) that integrates the difference between increase (new knowledge "NK") and decrease (erosion of knowledge "EK") in knowledge.

$$Kt = \int_{t0}^{t} \left[NK(s) - EK(s) \right] ds + K(t0)$$

New knowledge (NK) is positively affected by a fixed annual amount of possible overall knowledge which may be generated (OKG). OKG positively depends on the effect of absorptive capacity (EAC) and the effect of investments in knowledge (EIK) on the creation of new knowledge.

*NKt = OKG * (EACt + EIKt)*

To represent EAC, is specified a linear functional relation (graphic function as described in Appendix A.*a*) between knowledge acquisition through realised absorptive capacity (KA) and realised absorptive capacity (RAC) in which:

Min(KA) if RACt=0 (there is no RAC but the firm is still able to acquire some knowledge from outside "Min(KA)")

KA = ...

Max(KA) if RACt=1 (RAC is very high and consequently KA is very high, as well)

EACt= KA (time)

where KA is a function that specifies the effect of absorptive capacity on the increase in new knowledge over time.

EIK is equal to investments in knowledge (IK) multiplied by the evolution of the rate of knowledge creation through investments in knowledge over time (ERKC).

*EIKt = IKt * ERKCt*

To represent ERKC, is specified a linear functional relation (graphic function as described in Appendix A.*b*) between rate of knowledge creation through investments in knowledge (RKC) and time, in which RKC decreases as time passes according to Argote's view (1999).

Max(RKC) when time=0 years (RKC is very high at the beginning of the first generation)

RKC = ...

Min(RKC) when time=90 years (RKC is very low at the end of the third generation "Min(RKC)")

ERKCt = RKC (time)

[7] Accumulator means that the variable (in this case, knowledge) is accumulated over time.

where RKC is a function that specifies the evolution of the rate of knowledge creation through investments in knowledge over time.

Erosion of knowledge (EK) is affected by a fixed annual rate of knowledge erosion (α).

$EKt = Kt * \alpha$

<u>Representing outside industry knowledge to discover (INKD).</u> Outside industry knowledge to discover is the total outside industry knowledge which has not been discovered yet. It is represented as a stock (accumulator) that integrates the difference between increase (outside industry inventions "INI") and decrease (outside new industry knowledge "NINK") in outside industry knowledge to discover.

$$INKDt = \int_{t0}^{t} [INI(s) - NINK(s)]ds + INKD(t0)$$

Outside industry inventions (INI) refer to outside fundamental base inventions which are, at this time, not well explained yet. They still have to be discovered in order to be exploited. INI are modelled through a random function which generates inventions randomly because they cannot be predicted.

INIt = IF THEN ELSE (RANDOM UNIFORM (0, 1, 99632)>0.98,4,0)

Outside new industry knowledge (NINK) refers to the outside industry knowledge which has been invented, explained and can be exploited. It is affected by a fixed annual discovery rate (β).

$NINKt = INKDt / \beta$

<u>Representing outside industry knowledge (INK).</u> Outside industry knowledge is the total industry knowledge which exists outside the family firm. It is represented as a stock (accumulator) that accumulates over time from outside new industry knowledge (NINK).

$$INKt = \int_{t0}^{t} [NINK(s)]ds + INK(t0)$$

Therefore, NINK is the outflow of INKD and the inflow of INK (see figure 4).

<u>Representing potential absorptive capacity (PAC).</u> PAC is represented as a stock (accumulator) that integrates the change in PAC (Ch PAC).

$$PACt = \int_{t0}^{t} [ChPAC(s)]ds + PAC(t0)$$

Change in PAC (Ch PAC) depends on the relative knowledge (RK) of the family firm, that is, the percentage of the outside industry knowledge (INK) possessed by the family firm. RK is equal to the knowledge of the family firm (K) divided by the total industry knowledge outside the family firm (INK).

$RKt = Kt / INKt$

PAC is calculated with a first order exponential smoothing (information delay[8] from RK to PAC) of the observed value of RK, whose formulation is similar to an adaptive expectations mechanism (Forrester, 1961; Larsen and Lomi, 1999; Sterman, 2000; Mollona, 2000; Lomi, Larsen and Freeman, 2005).

Forrester (1961: 407,408) posits that "smoothing is a process of taking a series of past information values and attempting to form and estimate of the present value of the underlying significant content of the data. In particular, the exponential smoothing gives the greatest weight to the most recent value and attaches progressively less significance to older information".
Sterman (2000) explains exponential smoothing with the concept of adaptive expectations. Sterman (2000: 428,429) argues that "adaptive expectations mean the perceived or expected value (belief) gradually adjusts to the actual value of the variable. The expected value changes when it is in error, that is, when the actual value differs from the expected value of the variable. The state of the system adjusts (with an adjustment time, i.e. delay) in response to the gap between expected value and actual value".

According to the concepts mentioned above, change in PAC is given by:

$Ch\ PACt = (RKt - PACt) / Delay\ PAC$

where PAC is the expected value (or average); RK is the actual value; delay PAC is the information delay (time to average).
In other words, this process assumes that the gap between RK (actual value) and PAC (expected value) closes only gradually causing delays.

Representing realised absorptive capacity (RAC). RAC is represented as a stock (accumulator) that integrates the change in RAC (Ch RAC).

$$RACt = \int_{t0}^{t} [ChRAC(s)]ds + RAC(t0)$$

Change in RAC (Ch PAC) depends on the PAC of the family firm.

As before, RAC is calculated with a first order exponential smoothing (information delay from PAC to RAC) of the observed value of PAC, as follows:

$Ch\ RACt = (PACt - RACt) / Delay\ RAC$

[8] A temporal delay is defined as the amount of time by which an event is retarded.

where RAC is the expected value; PAC is the actual value; delay RAC is the information delay.
In addition, Ch RAC is positively influenced by the capabilities (C) of firm members (see figure 4).

*Ch RACt = [(PACt – PACt)/ Delay RAC]*Ct*

Representing capabilities (C). Capabilities are represented as a stock (accumulator) that integrates the difference between increase (new capabilities "NC") and decrease (erosion of capabilities "EC") in capabilities.

$$Ct = \int_{t0}^{t} \left[NC(s) - EC(s) \right] ds + C(t0)$$

New capabilities (NC) are positively affected by RAC and advanced dynamic capabilities (ADC); and negatively affected by family inertia (FI).

In addition, C is calculated with a first order exponential smoothing (information delay from RAC to C) of the observed value of RAC, as follows:

*NCt = {[(RACt – Ct)/Delay C] * ADCt}/FIt*

where C is the expected value; RAC is the actual value; delay C is the information delay.

Erosion of capabilities (EC) is affected by a fixed annual rate of capabilities erosion (γ).

*ECt = Ct ** γ

Representing advanced dynamic capabilities (ADC). Advanced dynamic capabilities are represented as a stock (accumulator) that integrates the difference between increase (new ADC "NADC") and decrease (erosion of ADC "EADC") in advanced dynamic capabilities.

$$ADCt = \int_{t0}^{t} \left[NADC(s) - EADC(s) \right] ds + ADC(t0)$$

New ADC (NADC) are positively affected by new capabilities which depend on 'the effect of change of capabilities on the creation of new ADC'(δ):

*NADCt= NCt ** δ

Erosion of ADC (EADC) is affected by a fixed annual rate of ADC erosion (ε).

*EADCt = ADCt ** ε

As shown above, a strong positive correlation exists between C and ADC (see figure 3). Indeed, NC influence the creation of NADC and the stock ADC influences the creation of NC (see figure 4).

Representing entrepreneurial performance (EP). Entrepreneurial performance is represented as a stock (accumulator) that integrates the difference between increase (creation of EP "CEP") and decrease (erosion of EP "EEP") in entrepreneurial performance.

$$EPt = \int_{t0}^{t} \left[CEP(s) - EEP(s) \right] ds + EP(t0)$$

Creation of EP (CEP) is positively affected by ADC at a fixed annual rate of entrepreneurial performance creation (ζ). A delay between the creation of ADC and the creation of EP (delay EP) is taken into consideration in the simulation model.

$CEPt = (ADC * \zeta)/Delay\ EP$

Erosion of EP (EEP) is affected by a fixed annual rate of EP erosion (η).

$EEPt = EPt * \eta$

Representing trans-generational value (TGV). Trans-generational value is represented as a stock (accumulator) that integrates the difference between increase (creation of TGV "CTGV") and decrease (family wealth "FW" and investments in knowledge "IK") in trans-generational value.

$$TGVt = \int_{t0}^{t} \left[CTGV(s) - FW(s) - IK(s) \right] ds + TGV(t0)$$

Creation of TGV (CTGV) is positively affected by EP at a fixed annual rate of TGV creation (θ). A delay between the creation of EP and the creation of TGV (delay TGV) is taken into consideration in the simulation model.

$CTGVt = (EPt * \theta)/Delay\ TGV$

Family wealth[9] (FW) is affected by a fixed annual rate of withdrawals (ι).

$FWt = TGVt * \iota$

Investments in knowledge (IK) are affected by a fixed annual rate of investments in Knowledge (κ).

$IKt = TGVt * \kappa$

[9] Family wealth is represented by the family's patrimony outside the family business, invested in fixed assets (such as land, buildings, etc.) and held in current assets (deposits, outside shares etc.).

Representing family inertia (FI). Family inertia is represented as a stock (accumulator) that integrates the change in family inertia (Ch FI).

$$FIt = \int_{t0}^{t} \left[ChFI(s)\right] ds + FI(t0)$$

Ch FI depends on the effect of paternalism on family inertia (EPFI).

FI is calculated with a first order exponential smoothing (information delay from EPFI to FI) of the observed value of EPFI, as follows:

Ch FIt = (EPFIt – FIt)/Delay FIt

where FI is the expected value; EPFI is the actual value; delay FI is the information delay.

To represent EPFI, it is specified a functional relation (graphic functions, as described in Appendix B) between paternalism (P) and time, considering four scenarios. The first scenario does not consider paternalism in the simulation, whereas the other three scenarios take into account three different evolutions of paternalism over three generations.

- **Scenario 1**: Basic case without paternalism.

- **Scenario 2**: Paternalism decreases over time (Appendix B.*a*).

$EPFIt_2 = P_2(time)$

where P_2 is a function that specifies the effect of paternalism on family inertia over time in scenario 2 (P decreases ➔ FI decreases).

- **Scenario 3**: Paternalism increases over time (Appendix B.*b*).

$EPFIt_3 = P_3(time)$

where P_3 is a function that specifies the effect of paternalism on family inertia over time in scenario 3 (P increases ➔ FI increases).

- **Scenario 4**: Paternalism fluctuates over time (Appendix B.*c,d,e*). Details in the next paragraph.

RESULTS AND NEW INSIGHTS

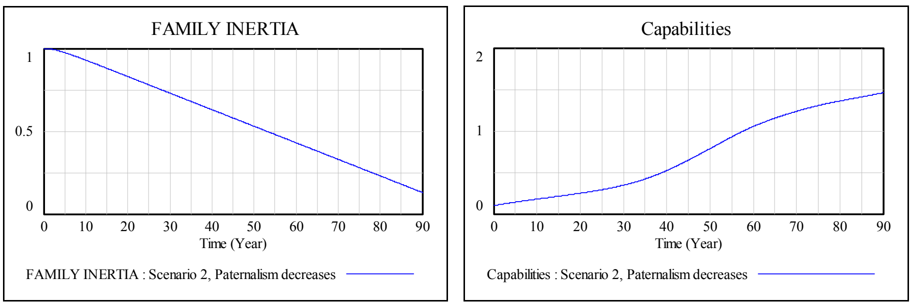
As mentioned before, we examine four different scenarios describing the evolution of paternalism over three generations in family business and the consequent effects on family inertia and capabilities, and then on the model as a whole.
Figure 7 shows the simulation results of the model over three generations (90 years) of a generic family firm considering scenario 1, scenario 2 and scenario 3.

Scenario 1: *Basic case without paternalism.* As it was expected, if knowledge (K) increases over three generations, basic dynamic capabilities (BDC: PAC and RAC), capabilities (C), advanced dynamic capabilities (ADC), entrepreneurial performance (EP) and trans-generational value (TGV) also increase through dynamic reinforcing loops (figure 7).
In particular, capabilities and dynamic capabilities (PAC, RAC and ADC) increase at a slower rate in the third generation (about from the 60th to 90th year) probably because psychological ownership[10] (including motivation and commitment) of family members usually decreases after the second generation, as pointed out by Astrachan et al., (2002).

Interesting results emerge when family inertia (as a function of paternalism) is included in the model.
Scenario 2, scenario 3 (figure 7) and Appendix B show the simulation results concerning the effect of paternalism on family inertia (EPFI) and the consequent effects on C, ADC, EP, TGV, K and BDC.

Scenario 2: *Paternalism decreases over time.* As paternalism decreases, family inertia decreases, as well. Consequently, the creation of capabilities increases (see figure 5) and a positive effect drives all the variables of the model (figure 7, Appendix B.*a*).
Results are similar to the first simulation (scenario 1) but values become higher due to the decrease in family inertia and diverge during the second and third generation.
For instance, the maximum value of knowledge at the end of the third generation is equal to 36.93 in scenario 1 and it is equal to 39.48 in scenario 2. The maximum value of trans-generational value at the end of the third generation is equal to 2.07 in scenario 1 and it is equal to 2.67 in scenario 2 (figure 7).

Figure 5: Effect of family inertia on capabilities in scenario 2

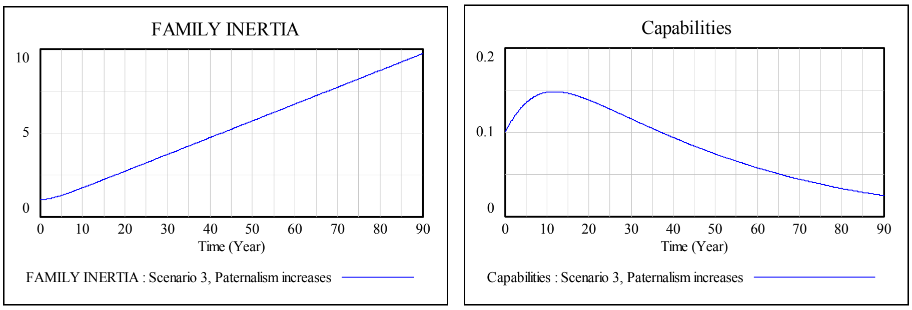


[10] *Psychological ownership* is the psychologically experienced-phenomenon where owners, managers and employees develop possessive feelings that the family firm is "mine" or "ours". For instance, strength of identifying oneself with the family business, sense of belonging to the family business, strong feeling of responsibility towards the family business and so on (Koiranen, 2006: adopted from Pierce et al., 2003).

Scenario 3: *Paternalism increases over time.* As paternalism increases, family inertia increases, as well. Consequently, the creation of capabilities decreases (see figure 6) and a negative effect drives all the variables of the model (figure 7, Appendix B.*b*).
The negative effect can be clearly observed for C, ADC, EP and TGV; whereas, K, PAC and RAC increase but their values become lower compared to the simulations made before and completely diverge during the third generation when usually problems rise (see Astrachan et al., 2002).
Results are consistent with the literature that stresses how critical is the third generation in family firms and how issues may be amplified during this generation (see Aronoff and Ward, 2001, Astrachan et al., 2002).
For example, the maximum value of knowledge at the end of the third generation is equal to 36.93 in scenario 1; it is equal to 39.48 in scenario 2; and it is equal to 24.99 in scenario 3 (figure 7).

A new *insight* emerges from the simulation of scenario 3. In fact, the creation of capabilities is not negatively influenced by the increase in family inertia at the beginning of the activity for about 10 years (see figure 6). Consequently, a positive effect drives advanced dynamic capabilities for about 10 years. The effect is even bigger for entrepreneurial performance and trans-generational value which keep on increasing for about 20-25 years (see figure 7).

Figure 6: Effect of family inertia on capabilities in scenario 3

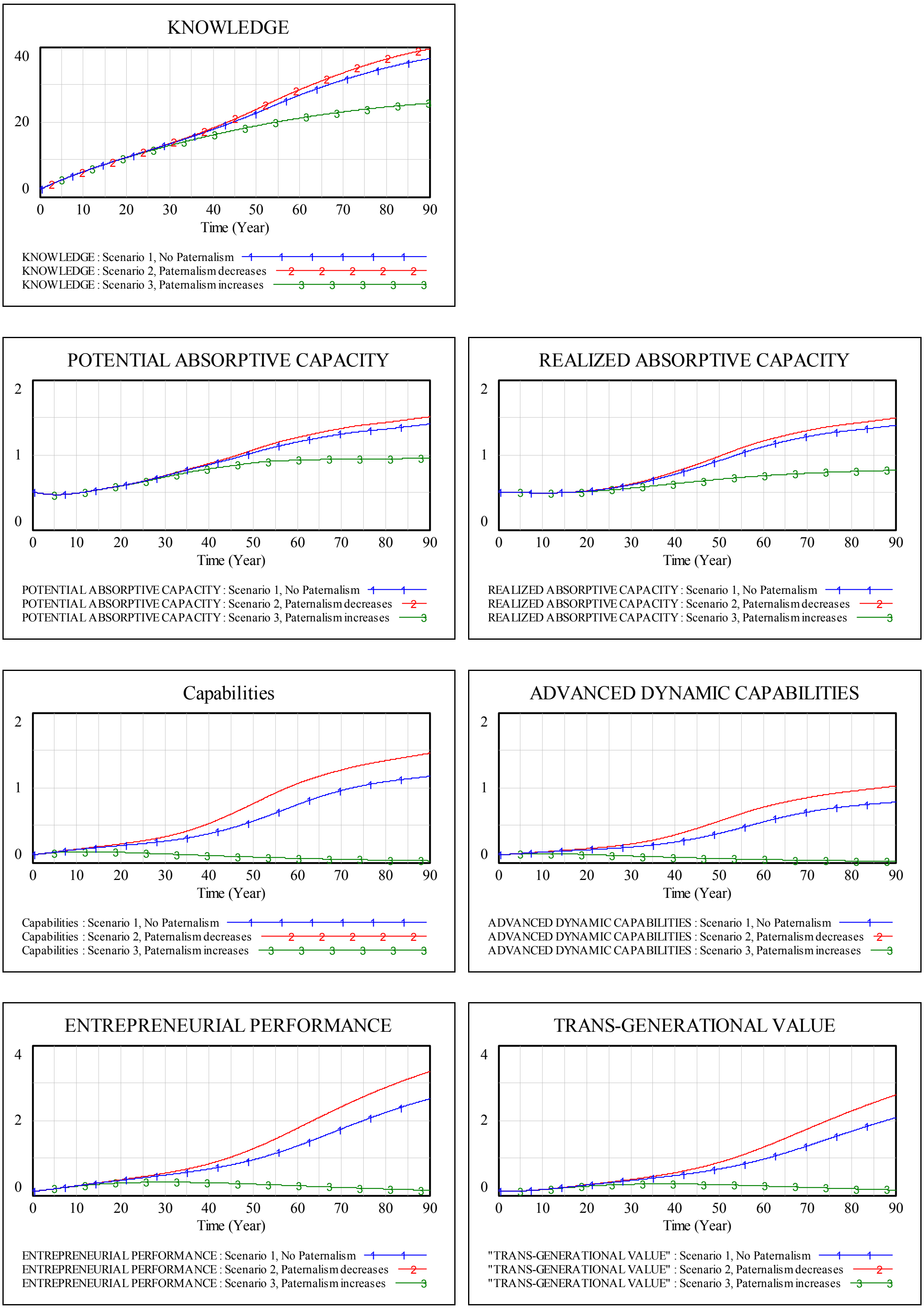


This behaviour / phenomenon can be explained going back to the definition of family inertia and the meaning of paternalism:

Family inertia is defined as the tendency of family firms to resist change even when it is needed to match the requirements of a changing environment. It is a function of paternalism which affects family inertia negatively. The ideology of paternalism is protective and dominating in a fatherly way with a strong attitude to preserve family firm's traditions and not to make changes.

But at the beginning of the activity a paternalistic behaviour may be seen to some extent positive in order to guide and train the new generation. Problems (caused by FI) rise if such paternalistic behaviour persists over time especially when the two generations work actively together as shown in figure 7 (from the 10th year). To explain better such an effect, we refer to the article of Giddings (2003). He posits that the founder of a family firm often has much energy and personality to run things his way. He is a paternalistic person but this is good at the beginning of the family firm when a mentor/leader is needed. Indeed, offspring must be guided and trained. But as time passes, a dominating and autocratic climate might predominate and make working conditions difficult for offspring, to express their ideas, to make autonomous choices and to make changes in the business for the good of the business (Giddings, 2003; Koiranen 2003; Chirico, 2006b). In other words, the paternalistic behaviour which was essential at the beginning of the activity may become less crucial if it persists over time preventing change even when it is needed. As a consequence, the effect of paternalism on family inertia increases more compared to before with negative effects on the creation of capabilities and dynamic capabilities (Larsen and Lomi, 2002; Collis, 1994; Sharma et al., 2005; Chirico, 2006b). A negative effect drives all the variables of the model.

Figure 7: Simulations in Scenario 1, 2 and 3



The results of scenario 3 allow us to consider a new scenario where paternalism fluctuates over time (scenario 4).

Scenario 4: *Paternalism fluctuates over time.* Paternalism does not affect much family inertia at the start-up and at the beginning of each generation for a certain period (τ). Then, it rises up to a peak but falls down again with the following generation. It is a kind of resetting clock process in which the behaviour described above recurs every generation.

As before, to represent the effect of paternalism on family inertia (EPFI), it is specified a functional relation (graphic function, as described in Appendix B.*c*) between paternalism (P) and time. It is assumed that τ is equal to 10 years (Scenario $4_{.1}$):

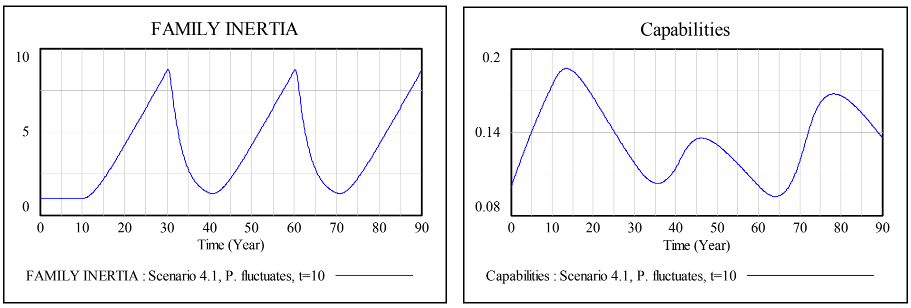
<u>(τ) = 10 years</u>

$EPFI_{4.1} = P_{4.1}$ *(time)*

where $P_{4.1}$ is a function that specifies the effect of paternalism on family inertia over time in scenario $4_{.1}$ with τ= 10 (P fluctuates ➔ FI fluctuates).

The simulation depicted in figure 10 and Appendix B.*c* show that when paternalism does not have much affect on family inertia at the beginning of each generation for about 10 years, C (see figure 8), ADC, EP and TGV keep on increasing. After that when the effect of paternalism on family inertia starts rising up to a peak while the two generations work actively together, C (see figure 8), ADC, EP and TGV are negatively influenced.

Figure 8: Effect of family inertia on capabilities in scenario $4_{.1}$



As before, this behaviour / phenomenon can be explained through the article of Giddings (2003): a paternalistic behaviour is essential at the beginning of the activity to guide and train offspring (EPFI very low) but may become less crucial if it persists over time preventing change even when it is needed (EPFI increases). With the following generation, the effect of paternalism on family inertia (EPFI) declines as a kind of resetting clock. In fact, the beginning of the new generation and the complete end of the previous one (which might represent a dramatic change in the business), can be thought

of as "resetting the clock" similarly to the resetting clock used by Amburgey et al., (1993) in describing the dynamics of organisational change and failure.
The behaviour above-described recurs every generation.
The increase in entrepreneurial performance and trans-generational value is very high during the first generation for about 25-30 years and then stabilises in the second and third generation, even though capabilities and advanced dynamic capabilities go up and down because of the effect of family inertia (figure 10).

Results become more significant with the assumption that paternalism does not affect much family inertia at the beginning of each generation for a longer period (i.e. τ =15 in scenario $4_{.2}$ and τ = 20 in scenario $4_{.3}$; see figure 10 and Appendix B.*d,e*):

<u>(τ) = 15 years</u>

$EPFI_{4.2} = P_{4.2}\ (time)$

where $P_{4.2}$ is a function that specifies the effect of paternalism on family inertia over time in scenario $4_{.2}$ with τ = 15 (P fluctuates ➔ FI fluctuates).

and

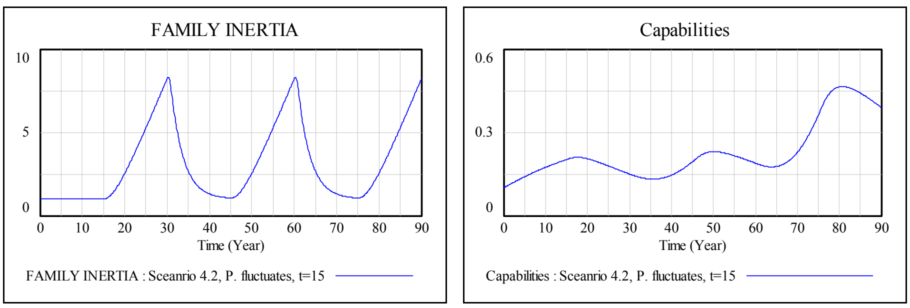
<u>(τ) = 20 years</u>

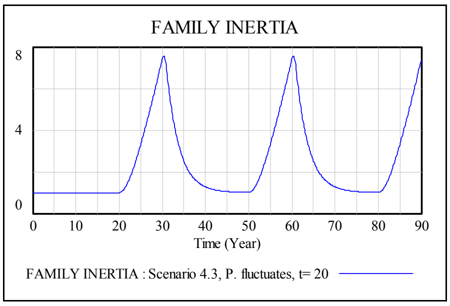
$EPFI_{4.3} = P_{4.3}\ (time)$

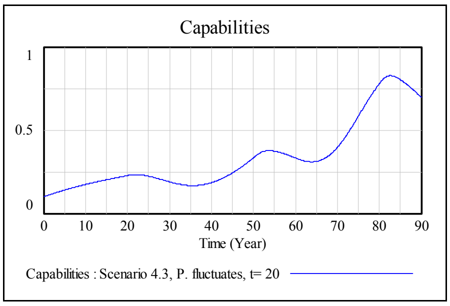
where $P_{4.3}$ is a function that specifies the effect of paternalism on family inertia over time in scenario $4_{.3}$ with τ = 20 (P fluctuates ➔ FI fluctuates).

As plotted in figure 10 when paternalism does not affect much family inertia at the beginning of each generation for a longer period, the family firm is able to better react to the period in which the effect of paternalism on family inertia increases. Indeed, C (see figure 9), ADC, EP and TGV increase over time but with some fluctuations in scenario $4_{.2}$ and $4_{.3}$.

Figure 9: Effect of family inertia on capabilities in scenario $4_{.2}$ and $4_{.3}$



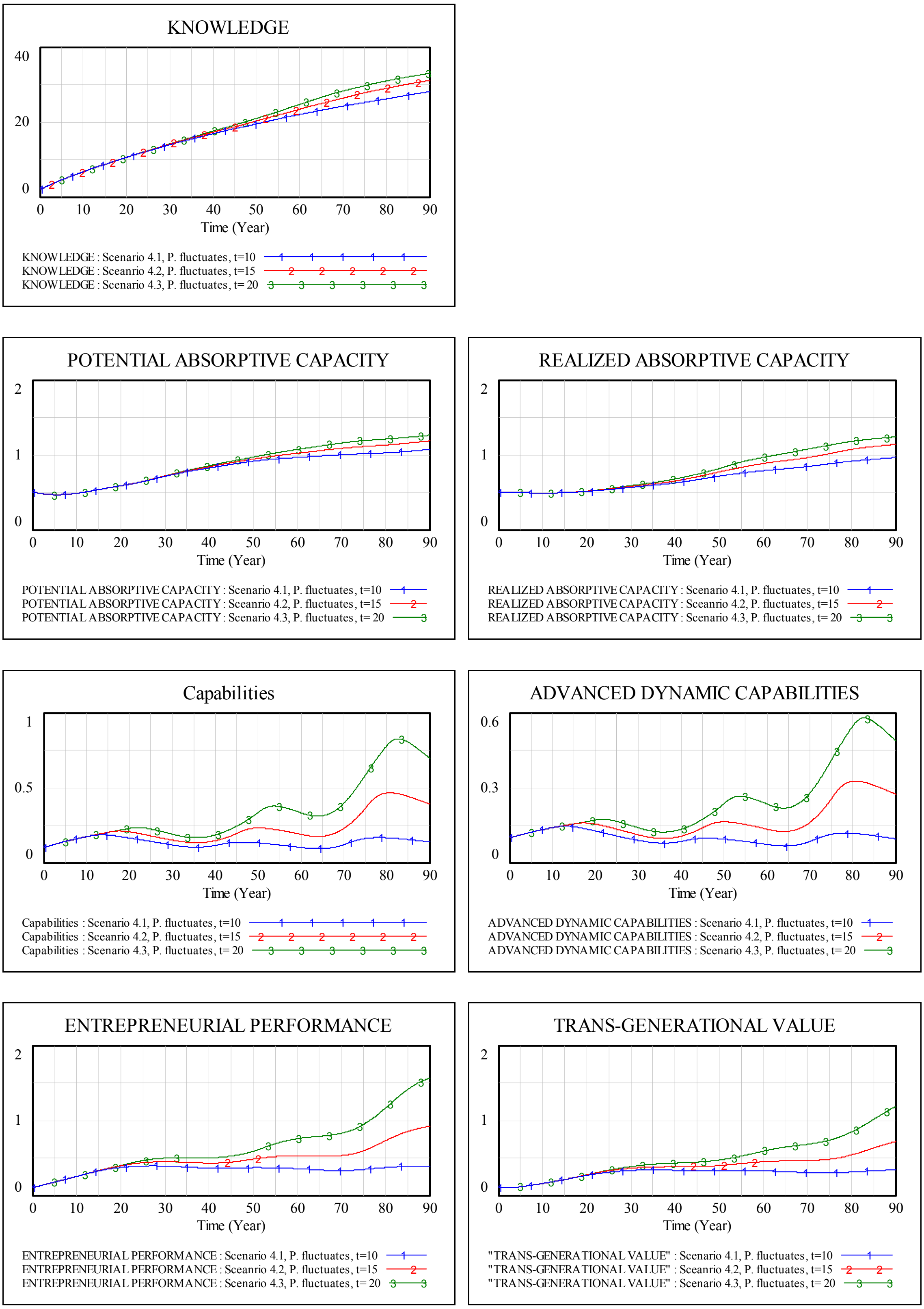




K, PAC and RAC keep on increasing following the same path during the first and the second generation in scenario $4_{.1}$, $4_{.2}$ and $4_{.3}$ and diverge during the third generation. For instance, at the end of the third generation the maximum value of knowledge is equal to 28.06 in scenario $4_{.1}$; it is equal to 31.05 in scenario $4_{.2}$; and it is equal to 33.02 in scenario $4_{.3}$ (figure 10).

In other words, the longer is "τ", the higher and faster is the increase of all the variables represented in the model (see figure 10). For example, at the end of the third generation the maximum value of TGV is 0.34 when "τ" is equal to 10 (scenario $4_{.1}$); it is 0.72 when "τ" is equal to 15 (scenario $4_{.2}$); and it is 1.18 when "τ" is equal to 20 (scenario $4_{.3}$).

Figure 10: Simulations in scenario 4.1, 4.2 and 4.3



DISCUSSION AND CONCLUSIONS

Bothner and White (2002) posit that simulation models are useful when in reducing the real world complexity, they almost inviolate the established facts and yield surprising insights for further exploration.

By using simulations, it was possible to explore further the dynamic feedback loops of figure 3 and test its internal consistency, representing variables as dynamic accumulation processes (stocks).
A simulation model (figure 4) was built using the system dynamics methodology and interesting results and new insights emerged as reported in this research. The dynamic model allowed us to test different sets of assumptions at the same time.

Simulations gave evidence of the positive dynamic relations between knowledge, basic dynamic capabilities, capabilities, advanced dynamic capabilities, entrepreneurial performance and trans-generational value (*Scenario 1, 2, 3* and *4*); the positive relation between paternalism and family inertia (*Scenario 2, 3* and *4*); and the negative relation between family inertia and capabilities, with some exceptions (*Scenario 2, 3* and *4*).

In particular:

- *Scenario 2*: if paternalism decreases, family inertia decreases, as well. Consequently, the creation of capabilities increases and a positive effect drives all the variables of the model (figure 7, Appendix B.*a*).
- *Scenario 3*: If paternalism increases, family inertia increases, as well. Consequently, the creation of capabilities decreases and a negative effect drives all the variables of the model (figure 7, Appendix B.*b*). However, the creation of capabilities is not negatively influenced by the increase in family inertia at the beginning of the activity with positive effects on the model.
- *Scenario 4*: Paternalism fluctuates over time. Paternalism does not affect much family inertia at the start-up and at the beginning of each generation for a certain period (τ). Then, it rises up to a peak but falls down again with the following generation. Problems (caused by family inertia) rise after "τ" years from the beginning of each generation when the effect of paternalism on family inertia increases. The longer is "τ", the better the family firm is able to react to the period in which the effect of paternalism on family inertia increases (figure 10, Appendix B.*c,d,e*).

Results become more evident and visible during the third generation when usually problems rise in family business. Indeed, according to the literature, the most critical period faced by family firms is the third generation, and the positive and negative effects of past events, decisions and behaviours may be amplified during this generation (see Aronoff and Ward, 2001, Astrachan et al., 2002; Bridge et al., 2003). Family firms should be able to understand the long-term effects and results of actual events, decisions and behaviours, and, at the same time, prevent their negative consequences. System dynamics may be a useful tool to achieve such a result.

John Sterman[11], who is a leading expert on system dynamics, explains in one of his business courses for managers, planners, and strategists (Sterman, 2006) that "in a world of growing complexity, many of the most vexing problems facing managers arise from the unanticipated side-effects of their own past actions. In response, organizations struggle to speed learning and adopt a more systemic approach. The challenge is to move past slogans about accelerating learning and 'thinking systemically' to practical tools that help managers understand complexity, design better operating policies, and guide effective change. System dynamics is a powerful framework for identifying, designing, and implementing high-leverage interventions for sustained success in complex systems".

For this reason, the study conducted here encourages family-business researchers to make use of this powerful methodology of system dynamics. Interesting results and insights may emerge and help researchers to better understand the complexity of dynamism in a family business context and assist family firms to better manage their business within the firm and the family.

Limitations of this paper are related to the assumptions made and the impossibility of representing the real trend/degree of paternalism of a generic family firm. The use of graphic converters (graphic functions) solved some of those problems for the simulation in system dynamics.

This research can be viewed as a contribution to the literature on the simulation of first-order models of theory-testing, and, partially, on the simulation of second-order models of theory building. More work and simulations are needed before generalising and building a new theory based on the results and insights of this study. Furthermore, in the future, specific components of the model may be disaggregated to focus on particular issues related to family businesses.

[11] Professor of Management at the Sloan School of Management, Massachusetts Institute of Technology and Director of MIT's System Dynamics Group.

REFERENCES

Aronoff, C., and Ward, J.L., (2001). Family business values: How to assure a legacy of continuity and success. *Family Business Leadership Series*, No. 12. Marietta, GA, Family Enterprise Publishers.

Amburgey, T.L., Kelly D., and Barnett, WP., (1993). Resetting the clock: The dynamics of organizational change and failure. *Administrative Science Quarterly,* Vol. 38, No. 1, pp. 51-73.

Argote, L., (1999). *Organizational learning: Creating, retaining, and transferring knowledge*. Boston, Kluwer Academic Publishers, Norwell.

Astrachan, J.H., Klein, S.B., and Smyrnios, K.X., (2002). The F-PEC scale of family influence: A proposal for solving the family definition problem. *Family Business Review*, Vol. 15 No. 1, pp. 45–58.

Barney, J., (1991). Firm resources and sustained competitive advantage. *Journal of Management*, Vol. 17, No. 1, pp 99-120.

Bothner, M., and White, H., (2001). Market orientation and monopoly power. *In Lomi and Larsen, (eds). Dynamics of Organizations*, AAAI/MIT- Press, Menlo Park, CA, pp. 182-209.

Bridge, S., O'Neil, K., and Cromie, S., (2003). *Understanding enterprise, entrepreneurship and small business*, Palgrave Macmillan.

Chirico, F., (2006a). Knowledge models in family business: Evidence from Switzerland. *Compendium on the Family Business Models Around the World (ten volumes).* Hyderabad: ICFAI. Gupta, Vipin; Levenburg, Nancy; Moore, Lynda; Motwani, Jaideep; and Schwarz, Thomas (eds.). University Press.

Chirico, F., (2006b). From knowledge to trans-generational value creation in family firms. A dynamic capabilities and cultural approach. *Family firms as arenas for trans-generational value creation: a qualitative and computational approach*. University of Jyvaskyla, Press.

Collis, D.J., (1994). Research note: How valuable are organizational capabilities?. *Strategic Management Journal*, Vol. 15, Special issue, pp. 143-152.

Eisenhardt, K.M., and Martin, J.A., (2000). Dynamic capabilities: What are they? *Strategic Management Journal*. Vol. 21, No. 10-11, pp. 1105-1121.

Forrester, J.W., (1961). *Industrial dynamics*, Cambridge, Productivity Press.

Forrester, J.W., (1968). Market growth as Influenced by capital investment. *Industrial Management Review*, Vol. 9, No. 2, pp. 83-105.

Fotion, N., (1979). Paternalism. *Ethics*, vol 89, No 2, pp. 191-198.

Giddings, T., (2003). Avoid these family business obstacles. *San Fernando Valley Business Journal*, March 17; *Los Angeles Business Journal*. October 13.

Habbershon, T.G., and Pistrui, J., (2002). Enterprising families domain: Family-influenced ownership groups in pursuit of transgenerational wealth. *Family Business Review*, Vol. 15, No. 3, pp. 223–238.

Hanneman, R., Collins R., and Mordt, G., (1995). Discovering theory dynamics by computer simulation: Experiments on state legitimacy and imperialist capitalism. *Sociological Methodology*, ed. P. Marsden, pp. 1-46. Oxford: Blackwell.

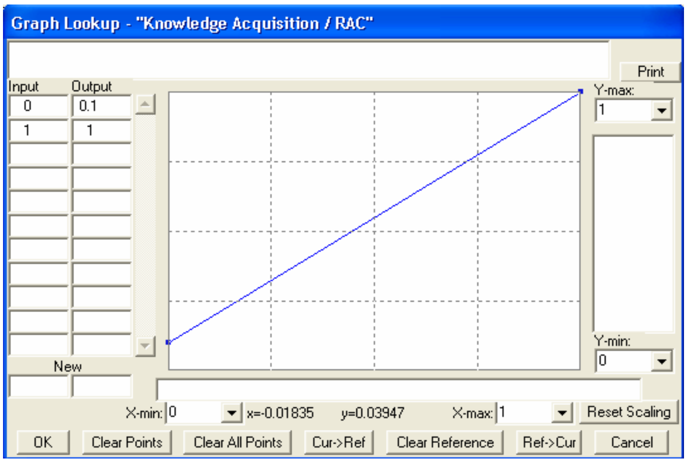
Koiranen, M., (2004): Entrepreneurialism, managerialism and paternalism as clashing ideologies in family business systems. *In Watkins, D. (ed.): ARPENT, Annual Review of progress in Entrepreneurship Research*: 2, 2002-2003, Brussels, pp. 299-310.

Koiranen, M., (2006). Psychological ownership and entrepreneurial drive as value creators. *Family firms as arenas for trans-generational value creation: a qualitative and computational approach*. University of Jyvaskyla, Press.
Johannisson, B., and Huse, M., (2000). Recruiting outside board members in the small family business: an ideological challenge. *Entrepreneurship and Regional Development*, Vol. 12, No. 4, pp. 353-378.
Johannisson, B., (2002). Energising entrepreneurship. Ideological tensions in the medium-sized family business. *In Fletcher, D (ed.) Understanding the Small Family Business.* London: Routledge, pp. 46-57.
Larsen, E., and Lomi A., (1999). Resetting the clock: A feedback approach to the dynamics of organizational inertia, survival and change. *Journal of the Operational Research Society,* Vol. 50, No 4, pp. 406-421.
Larsen, E., and Lomi, A., (2002). Representing change: A systems model of organizational inertia and capabilities as dynamic accumulation processes. *Simulation Modelling Practice and Theory*, Vol 10, Special Issue, pp. 271-296.
Lomi, A., and Larsen, E., (2001). Dynamics of organizations: Computational modeling and organization theories, AAAI/MIT- Press, Menlo Park.
Lomi, A., Larsen, E., and Freeman J., (2005). Things change: Dynamic resource constraints and system-dependent selection in the evolution of organizational populations. *Management Science*, Vol. 51, No 6, pp. 882-903.
Masuch M., (1995). Computer models. *Encyclopedic Dictionary of Organizational Behaviour*, ed. N. Nicholson, 91-92. London: Blackwell.
Mollona, E., (2000). *Analisi dinamica dei sistemi aziendali*; EGEA.
Morecroft, J.D.W., (1982). A critical review of diagraming tools for conceptualizing feedback system models. *Dynamica,* Vol. 8, No. 1, pp. 20-29.
Morecroft, J.D.W., (1983). System dynamics: Portraying bounded rationality. *Omega*, Vol. 11, No. 2, pp. 131-142.
Morecroft, J., and Sterman, J., (1992). Modeling for learning organizations. *European Journal of Operational Research*. Vol 59, No.1.
Oreskes, N., Shrader-Frechette, K., and Berlitz, K., (1994). Verification, validation, and confirmation of numerical models in the earth sciences. *Science*, Vol. 263, pp. 641-646.
Pierce, J., Kostova, T., and Dirks, K., (2003). The status of psychological ownership: Integrating and extending a century of research. *A Review of General Psychology,* Vol. 7, No. 1, pp. 84-107.
Sastry, M.A., (1997). Problems and paradoxes in a model of punctuated organizational change. *Administrative Science Quarterly*, Vol. 42, No. 2, pp. 237-275
Senge, P., and Sterman, J., (1992). Systems thinking and organizational learning: Acting locally and thinking globally in the organization of the future. *European Journal of Operations Research*, Vol. 59, pp. 137-150.
Sharma, P., and Manikutty, S., (2005). Strategic divestments in family firms: Role of family structure and community culture . *Entrepreneurship Theory and Practice*, Vol. 29, No. 3, pp. 293-312.
Sterman, J., (1992). *System dynamics modeling for project management*. MIT Cambridge MA 02139.
Sterman, J., (2000). *Business dynamics, systems thinking and modeling for a complex world*. New York, McGraw-Hill.

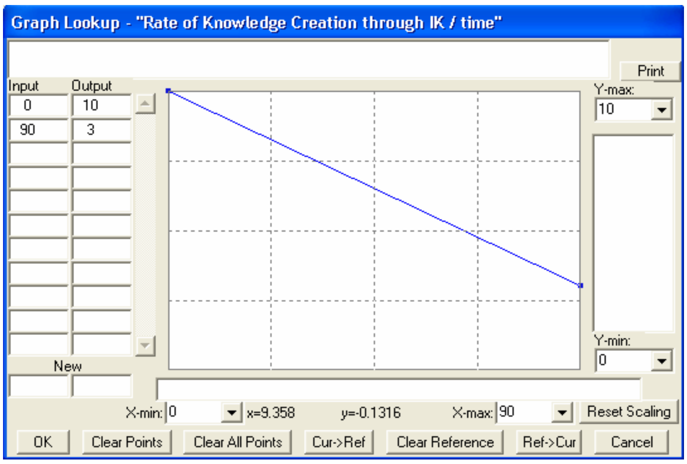
Sterman, J., (2006). Business Dynamics. MIT's approach to diagnosing and solving complex business problems. MIT Sloan, Executive Education. http://bmitsloan.mit.edu/execed/epp/courses/busdynamics06.pdf
Sutton, R, and Straw, B., (1995). What theory is not. *Administrative Science Quarterly*, Vol. 40, No. 3, pp. 371-785.
Teece, D.J., Pisano, G., and Shuen, A., (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, Vol 18, No. 7, pp 509-533
Van Ackere, A., Larsen E.R., and Morecroft J.D.W, (1993). Systems thinking and business process redesign: an application to the Beer Game. *European Management Journal,* 11:412-423.
Winter, S., (2003). Understanding dynamic capabilities. *Strategic Management Journal*, Vol. 24, No. 10, pp. 991-995.
Zahra, S.A., and George, G., (2002). Absorptive capacity: A review, reconceptualization, and extension. *Academy of Management Review*, Vol. 27, No. 2, pp. 185-203.

Appendix A

a- Relation between KA (Y-axis) and RAC (X-axis)

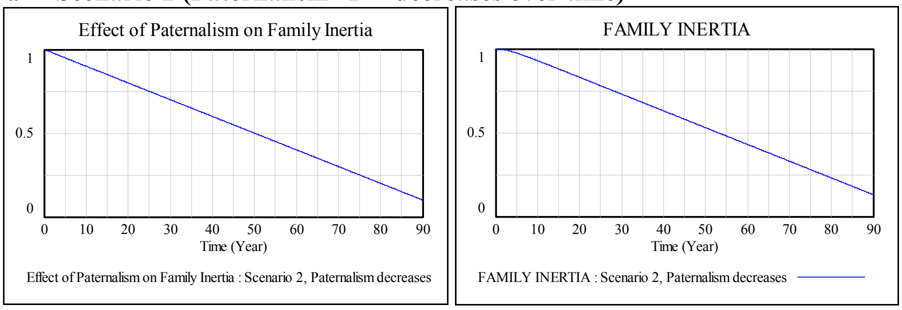


b- ERKC: relation between RKC (Y-axis) and time (X-axis)

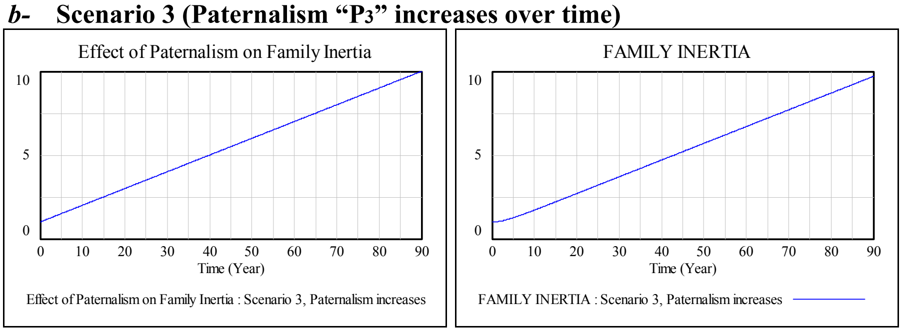


Appendix B: ‘Effect of paternalism on family inertia’ and ‘family inertia’

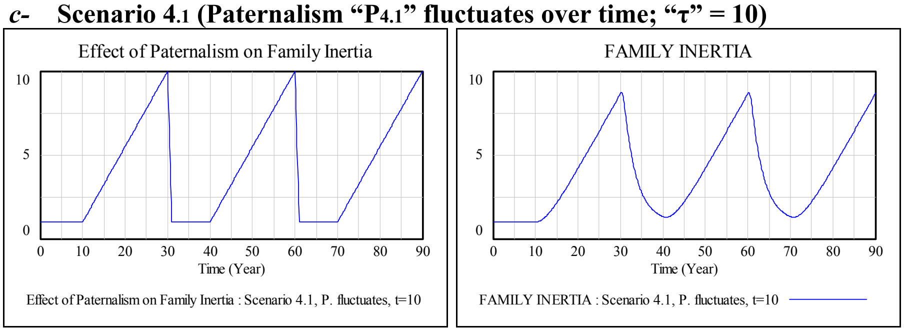
a- Scenario 2 (Paternalism “P2” decreases over time)



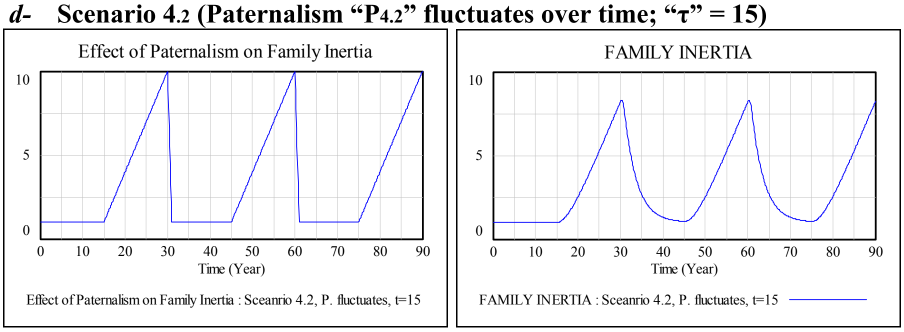
b- Scenario 3 (Paternalism “P3” increases over time)



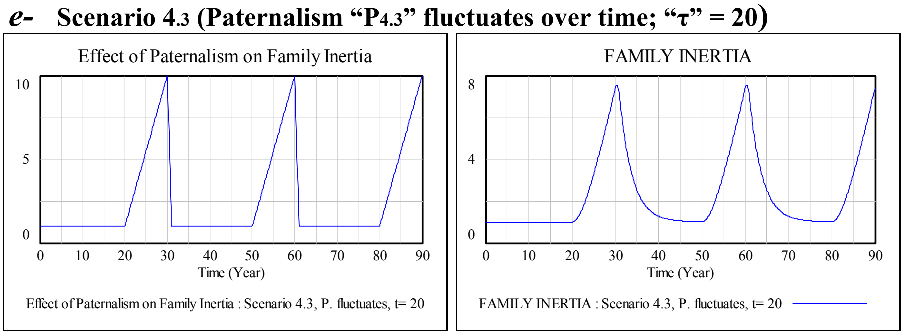
c- Scenario 4.1 (Paternalism “P4.1” fluctuates over time; “τ” = 10)



d- Scenario 4.2 (Paternalism “P4.2” fluctuates over time; “τ” = 15)



e- Scenario 4.3 (Paternalism “P4.3” fluctuates over time; “τ” = 20)



Min and Max of paternalism in scenario 2, 3 and 4

Max(P_2) when time = 0 years (*P_2 is at its maximum value at the beginning of the first generation)*

P_2 = ...

Min(P_2) when time = 90 years (*P_2 is at its minimum value at end of the third generation)*

Min(P_3) when time = 0 years (*P_3 is at its minimum value at end of the third generation)*

P_3 = ...

Max(P_3) when time = 90 years (*P_3 is at its maximum value at the end of the third generation)*

Min($P_{4.1}$) when 0<time<10 years

...

Max($P_{4.1}$) when time = 30 years

Min($P_{4.1}$) when 31<time<40 year

$P_{4.1}$= ...

Max($P_{4.1}$) when time = 60 years

Min($P_{4.1}$) when 61<time< 70 years

...

Max($P_{4.1}$) when time = 90 years

Min($P_{4.2}$) when 0<time<15 years

...

Max($P_{4.2}$) when time = 30 years

Min($P_{4.2}$) when 31<time<45 year

$P_{4.2}$ = ...

Max($P_{4.2}$) when time = 60 years

Min($P_{4.2}$) when 61<time< 75 years

...

Max($P_{4.2}$) when time = 90 years

Min($P_{4.3}$) when 0<time<20 years

...

Max($P_{4.3}$) when time = 30 years

Min($P_{4.3}$) when 31<time<50 year

$P_{4.3}$ = ...

Max($P_{4.3}$) when time = 60 years

Min($P_{4.3}$) when 61<time< 80 years

...

Max($P_{4.3}$) when time = 90 years

Appendix C

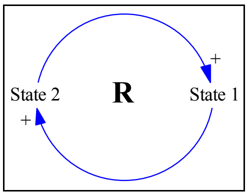
Variables

Sector	Variable	Type	Value
K	K	Initial Value	2
K	OKG	Constant	1
K	Min(KA)	Constant	0.1
K	Max(KA)	Constant	1
K	Min(RKC)	Constant	3
K	Max(RKC)	Constant	10
K	α	Constant	0.03
INKD	INKD	Initial Value	12
IK	IK	Initial Value	4
INKD and IK	β	Constant	8
PAC	PAC	Initial Value	0.5
PAC	Delay PAC	Constant	3
RAC	RAC	Initial Value	0.5
RAC	Delay RAC	Constant	3
C	C	Initial Value	0.1
C	Delay C	Constant	3
C	γ	Constant	0.05
ADC	ADC	Initial Value	0.1
ADC	δ	Constant	0.7
ADC	ε	Constant	0.05
EP	EP	Initial Value	0.1
EP	ζ	Constant	0.6
EP	Delay EP	Constant	3
EP	η	Constant	0.05
TGV	TGV	Initial Value	0.1
TGV	θ	Constant	0.4
TGV	Delay TGV	Constant	3
TGV	ι	Constant	0.1
TGV	κ	Constant	0.05
FI	FI	Initial Value	1
FI	Delay FI	Constant	3
FI	Min(P_2)	Constant	0.1
FI	Max(P_2)	Constant	1
FI	Min(P_3, $P_{4.1}$, $P_{4.2}$, $P_{4.3}$)	Constant	1
FI	Max(P_3, $P_{4.1}$, $P_{4.2}$, $P_{4.3}$)	Constant	10
FI	τ	Constant	10; 15; 20

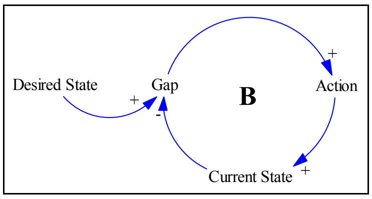
Appendix D

Positive and negative feedback loops

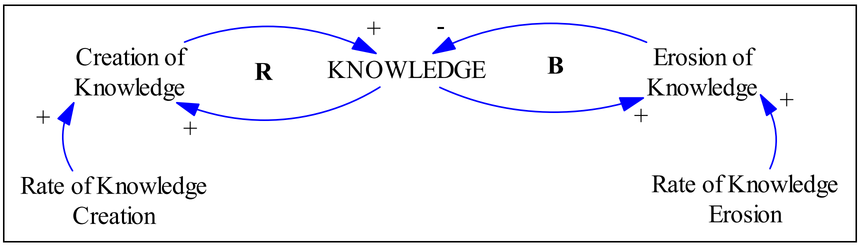
a. *Reinforcing Loop* (**R**) is a structure which feeds on itself to produce growth or decline: 'State 1' (the cause) increases or decreases 'State 2' (the effect) which, in turn, increases or decreases 'State 1', respectively. In other words, R tends to reinforce or amplify whatever is happening in the system. Of course, nothing grows forever. There must be some limits to growth which are created by negative feedbacks (Sterman, 2000):



b. *Balancing Loop* (**B**) counteracts and opposes change. It attempts to move some 'Current State' to a 'Desired State' (it is assumed that 'Current State' is lower than 'Desired State') through some 'Action': the 'Desired State' interacts with the 'Current State' to produce a 'Gap'. The larger the 'Gap', the stronger the influence to produce 'Action'. The 'Action' taken then moves the 'Current State' toward the 'Desired State' reducing the 'Gap' to zero:



An example will be helpful to clarify the above concepts. Figure 2 shows a simplified representation of the causal loop diagrams of knowledge in which the two feedback loops described above emerge (**R** and **B**):



'Knowledge' is positively influenced by the 'creation of knowledge' and negatively influenced by the 'erosion of knowledge'. 'Creation of knowledge' is given by 'knowledge' multiplied by the 'rate of knowledge creation', whereas 'erosion of knowledge' is given by 'knowledge' multiplied by the 'rate of knowledge erosion'.

Two balancing loops can be identified:

1. *Reinforcing loop* (**R**):
- Positive relation between ‘creation of knowledge’ and ‘knowledge’: the more knowledge is created, the more knowledge is accumulated;
- Positive relation between ‘knowledge’ and ‘creation of knowledge’: the more knowledge is accumulated, the more knowledge is created.
2. *Balancing loop* (**B**):
- Negative relation between ‘erosion of knowledge’ and ‘knowledge’: the more knowledge is eroded, the less knowledge is accumulated;
- Positive relation between ‘knowledge’ and ‘erosion of knowledge’: the more knowledge is accumulated, the more knowledge is eroded.

Balancing and reinforcing loops can be identified by counting the number of “-” and “+” in the feedback loop. A feedback loop is a balancing loop if the number of “-” is odd; it is a reinforcing loop if the number of “-” is even or zero.