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## **Lessons from Korean Development Experience**

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## Abstract

The main purpose of this paper is to explore the possibilities of learning from Korea some pertinent lessons for industrialization and development in the 21<sup>st</sup> century. The 21<sup>st</sup> century presents an even greater challenge for industrialization in the developing world than the post-WWII period. The changed global economic and ecological environment will shape the emergence of new technological and industrial paradigms and trajectories in significant ways. However, the experience of Korea still presents many relevant lessons. The paper uses an extension of Sen's idea of capabilities within a framework of complex dynamic systems. In this view, development is really an extension over time and space of freedom, particularly the positive freedom to lead a certain type of life an individual has reasons to value through the creation of an interlinked network of institutions. I discuss a number of strategic features of Korean development experience ranging from strategic openness to learning, innovation and ultimately, enhancing the standard of living for all. From the Korean case, it is apparent that the desirable institutions provide a rough and ready type of security of property rights, enforceability of contracts and lead to a gradual and strategically conceived integration with the world economy. In addition, they also help maintain macroeconomic stability without a necessarily rigid conservative fiscal stance. Over time and given sufficient financial development, the state and private sector institutions should be able to manage risk-taking by financial intermediaries. In order to promote equitable growth there will also need to be institutions that can supply social insurance and safety nets, and create a democratic space for voice and accountability. But there is no one-size-that-fits-all for any of these functions. I also argue that in addition to the positive lessons from the Korean experience and the willingness of Korea to extend aid and expertise to developing economies of Asia and Africa in particular, Korea can also play a much broader and significant role in the present turbulent global political economy through creative regional and global cooperation.

## 1. Introduction

The main purpose of this paper is to explore the possibilities of learning from Korea some pertinent lessons for industrialization and development in the 21<sup>st</sup> century. The 21<sup>st</sup> century presents an even greater challenge for industrialization in the developing world than the post-WWII period. The changed global economic and ecological environment will shape the emergence of new technological and industrial paradigms and trajectories in significant ways (Dosi 2000, Khan 2004a). However, the experience of Korea still presents many relevant lessons. Therefore, the next section focuses on the development and industrialization experiences of Korea in order to bring out a number of still relevant insights. The strategy of my paper is to both avoid the danger of falling into overgeneralization and to emphasize the need for some changes in both the global economic environment and specific development and industrialization strategies. This is highlighted in section 2 of this paper where the outlines of an alternative development strategy are given.

It should be noted at the outset that even during the post-WWII period, as some have pointed out (e.g., Amsden(2008), Jomo(2007,2001,1995), Khan (2004a,b; 1997), there were at least two sub-periods. The first was an era of relative optimism during the Bretton Woods period of managed global capitalism. During this era, there was an overall strategy of development in the capitalist bloc that relied to a large extent on state-market synergy. It delivered fairly high growth for at least two decades in many countries but the distributional record was not impressive. Most importantly, the East Asian miracle with high growth and relatively benign distributional record throughout the entire post-WWII period(except the post-1990 record of Korea) also had its beginning during this era. Much of the infrastructural and human resources foundations

for the subsequent growth and industrialization in the four tigers--- and in retrospect, for Korea and India--- were laid during these two decades.

The second period---now that much of the smoke from the last thirty years has cleared-- - can be seen now as the demise of the Bretton Woods international financial architecture without any firm replacement except a dollar hegemony which now looks increasingly shaky. It is also seen as the era of Washington consensus which promised much but has delivered so far very little in the way of growth, investment and employment. Admittedly, both the periods were complex and a nuanced history is yet to be written; but the contrast is there. The rise of the Asian tigers including Korea and to some extent India has to be seen against this background. In this paper, the main argument regarding sustainable industrialization and development in this century is based on the idea of a complex economic system. The main conclusion is that while industrialization is both necessary and possible, a reasonable strategy must take into account the unevenness and complexity of the global economic system. Given that the developing countries themselves are at several different stages of development, there is no one-size-fits-all set of prescriptions. However, a nuanced and context-sensitive approach based on a realistic theory of development can still offer much help. This is where the Korean experience, I will argue, still has much to teach us.

Writing in 1926, in a biographical essay on Edgeworth, Keynes underlined some of the problems of complex human systems:

We are faced at every turn with problems of organic unity, of discreteness, of discontinuity--- the whole is not equal to the sum of the parts, comparisons of quantity fail us, small changes produce large effects, the assumptions of a uniform and homogeneous continuum are not satisfied.<sup>1</sup>

If anything, the developing part of the world economy today shows to even a greater degree the kind of complexity captured in Keynes's words above. Fortunately, systems theory and economic theory have both made some progress since those dark days. Although we are far from a genuinely complete theory of complex economic systems,

efforts are underway that have already borne some interesting fruit in several limited areas.<sup>2</sup> There are many facets of complex developing economies --each with its own sub-systemic characteristics to be sure, but there are also some common strategic features. The purpose of this paper is to partly synthesize from a strategic perspective-- - to the extent it is possible to do so--- the development experiences of mainly the Asian economies with references to others( particularly the BRICs as a group and the Least Developed Countries---the LDCs--- by way of contrast) and draw some appropriate lessons for industrialization and development in the 21<sup>st</sup> century..

## **2. Defining Development and Stages of Development and Some Common Strategic Features**

However, at this point some clarification of the key term "development" is necessary in order to avoid ambiguities and confusions. In the rest of this paper, I will be referring to three concepts of development that are implicit in much of the discussion in the field of industrialization and development. The first is the idea of development as growth with some structural change or at least the idea that this type of growth is the most crucial necessary condition for development. The second concept is derived by adding explicit distributional elements to growth--- particularly inequality and poverty. Both these ideas are shared by the development economists today ---at least implicitly. In a recent contribution, Peter Warr is explicit in discussing all three---growth, absolute poverty and inequality<sup>3</sup>--- and his thoughtful essay alerts the reader to the performance of Thailand in all three areas and derives--- at least partly--- a logic of further necessary reforms following from his cogent analysis of the three aspects of development in this sense. . He concludes:

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<sup>1</sup> Keynes(1971-9), Vol. X, p. 261

<sup>2</sup> See for example, Khan(2004a,b, 2003a,, 1998,1997) and the references therein.

<sup>3</sup> At least since the McNamara period in the 70s, the World Bank took the lead in advocating "redistribution with growth". ILO and UNCTAD also followed suit and had stronger lines of argument. Sen did his earlier work on poverty in the 70s under ILO sponsorship. UNIDO and ECLAC both had always advocated industrialization and equity.

Not all aspects of the Thai development strategy have been similarly successful. Inequality has increased at the same time as absolute poverty has declined. The underlying causes of this increase in inequality are still not well understood. (Warr 2008, p.22)<sup>4</sup>

The third--- and the broadest approach to development discussed here--- is in terms of Sen's idea of capabilities and its further extensions. In this view, development is really an extension over time and space of freedom, particularly the positive freedom to lead a certain type of life an individual has reasons to value. In technical modeling of industrialization and development (including my own models---see appendixes) often this normative view is not adopted explicitly. Yet, in so far as there is a normative aspect about development being a "(public) good" that is a premise for the whole project of industrialization and development such a view is consistent with the modeling approaches as well. In a recent essay prepared for WIDER, a Korean scholar Keun Lee's perceptive comments on the possible role of democracy in development extends considerably the terrain of discussion in the direction of the "development as freedom" perspective when he writes:

We see obvious advantages in democracy, amongst which is the convenient feature that citizens are not subject to arbitrary arrest and torture. Truly strong states get it wrong more often than they get it right. Thus the military dictatorships of Latin America left little in the way of legacy, whereas the military dictatorships in Korea and Taiwan (while not on anything like the same scale of brutality) left a powerful legacy of development. The difference lies clearly in strategic orientation and in institutional capacity in formulating and implementing a program of national industrial development. Our point is that this is an option available to the political leadership of any developing country today. On top of this, the key to the Korean or Asian success was institutional longevity. (Lee 2008, p. 13)

It would seem, therefore, that there is an implicit agreement in at least the post-1970 thinking that development is "growth plus" other things. While the list of "other things" may vary somewhat, none of the researchers in the field today would equate growth and development. Yet, almost all would agree that generating high growth may be a useful means towards development. Many thoughtful researchers also pay some attention to what can be called "the political economy of growth and distribution"

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<sup>4</sup> See also Warr(1993,1999,2005) for nuanced analyses of the various aspects of Thailand's development experience and Jomo(2007,1995) for Malaysia..

Synthesizing the Experiences of the high growth Asian economies and the Korean economy in particular further reveals some common strategic orientations as well as the effects of changes in external environment and shifts in policies over time. This is consistent with the characteristics of complex economic systems which are nonlinear with multiple equilibria and path dependence. Over time, one may observe the emergence of structural shifts in some cases, stagnation in other cases depending on initial conditions, strategies, policies and external environment among other things. In the Asian cases discussed here, there are many specific variations within each. However, they also share to various degrees many specific features listed below.

### **1. Strategic Openness of the Korean strategy:**

One important feature of the Korean strategy was a strategic commitment to export promotion beyond an earlier period of strategic import substitution(SISI)<sup>5</sup> and further goals of moving up the value added ladder. It should be kept in mind however, that there can be a "fallacy of composition"(Cline1982, Khan 1983,Mayer 2002, Razmi and Blecker 2006) in claiming that all developing countries need to do is to pursue an export-led growth policy. Reciprocal demands may not exist sufficiently and the ensuing competition for export markets in developed countries may create winners as well as losers. Therefore, what may be needed in the future for other aspiring countries is a strategic approach including the development of national and regional markets and the creation of dynamic comparative advantage along with a number of other policies and institution building processes described below. In Asia, Korea and other East Asian successful countries can play a significant enabling role in this respect in the future.

**2. Heterodox macroeconomic policies for stability<sup>6</sup>**---Here Korea has displayed more of a mix of heterodox policies than the standard Washington consensus. For a long time capital markets were not liberalized. Trade policy, on the other hand, was more liberal; but here, too, it was combined with industrial policies(Chang 2007) It

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<sup>5</sup> On what I have called SISI, see Amsden(2008) and the references therein, Bruton(1998)Khan(2004a,b;1997,1985,1982a,b)

<sup>6</sup> See Jomo and Nagaraj(2001) for a good discussion of heterodoxy in this context.

seems that the rigidity of Washington consensus particularly in this area is rejected by the experiences of developing economies like Korea.

**3. Creation of institutions for productive investment---** Korea seems to have gone much further than even the other successful East Asian countries much earlier. Starting with the reforms in the 1960s, it moved through several successive stages and is now trying to find appropriate technological niche in a world that is moving towards a convergence of information, bio and nano technologies by 2050. The role of state in the creation of these institutions is still very prominent.

**4. Agricultural development---** Korea and Taiwan had an egalitarian land reform after the end of Japanese colonialism. Although, the agricultural policies underwent some swings in Korea, until the WTO regime an emphasis on helping the small farmers was quite notable. Technological change in agriculture in both Korea and Taiwan has been quite impressive.

**5. Industrial development and structural change--** the strategic perspective in this important area suggests that the successful countries to various degrees pursued a continuously unfolding and dynamic set of policies with much trial and error. The retrospective attempts to tell a coherent story have often led to an overly deductive picture where good performances supposedly follow from a few, usually neoclassical economic principles. The Korean case studies by Amsden and Khan show the complexity of the challenges and the trial and error responses by the policy makers over several decades. Amsden(1989, 2008), Khan(1982a,b;1983,1997,2004a,b) and Wade(1990) discuss the cases of Korea and Taiwan in the general East Asian context.

**6. Creation of technological capabilities---** here the Korean case stands out as a very apt illustration of creating technological capabilities throughout the entire growth and development trajectory in definite stages.<sup>7</sup>

As Lee(2008,pp.4-5) points out:

Among various aspects of capacities, emphasis should be on technological capabilities because without these, sustained growth is impossible. In this era of open market competition, private companies cannot sustain growth if they rely upon cheap products; they need to be able to move up the value-chain to higher-value added goods based on continued upgrading and improvement and technological innovation. Furthermore, private companies had better be “local” companies, whenever possible, including locally controlled JVs, not foreign controlled subsidiaries of the MNCs. MNCs subsidiaries are always moving around the world seeking cheaper wages and bigger markets. Therefore, they cannot be relied upon to generate sustained growth in specific localities or countries although they can serve as useful channels for knowledge transfer and learning.

**7. Technological learning and innovation---** creating national innovation systems in particular requires the creation of specific institutions and technological learning over time. Ultimately, if development is to continue beyond the catching up phase, this may present the most crucial set of policy challenges. Here, the paper on Korea by Lee(2008) is an admirable attempt to sum up the lessons. There are specific features here to which Lee(2008,p.5) draws our attention.

Therefore, while the ultimate goal and criterion of development is to raise the capabilities of local private companies, the process needs pilot agencies to guide and coordinate the whole process. Such needs exist because key resources are so scarce, and thus had better... be mobilized for uses in sectors or projects with greatest externalities. As understood by Gerschenkron, who analyzed the latecomer industrialization of Germany and Russia, and identified latecomer agencies, such as large state-owned investment banks to drive the process in these countries, it is such agencies that can make up for gaps or lacunae in the country that is seeking to industrialize. All the East Asian countries built specific state-agencies that played a role of guiding the process of industrialization. In Korea the institutions established in the 1960s under the Park regime included the Economic Planning Board to set economic plans; the Ministry of Trade and Industry to support industrial policy and export; and the Ministry of Finance to finance economic plans.

Both state and civil society have to play important roles. At an earlier stage, the state necessarily plays a large and activist role . At a later stage, however, the creation of technological capability has to rely on a private-public partnership at both the precompetitive and the competitive phases of innovation(Khan 1998,2004a, 2010).

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<sup>7</sup> See also Lee(2006) for a contrast of Korean experience with the Washington consensus and Khan(2008, 2002,1998 and 1997) for a discussion of the Korean ( and Taiwanese)case(s) in the context

**8. Direct Foreign Investment and Foreign Aid---** these factors have played a role for Korea. Investment from abroad has perhaps been more significant than aid per se. However, internal generation of investible funds and public sector support have also played a crucial role.

**9. Poverty reduction strategies--** these are a varied set of policies that are necessary in addition to growth. Although growth is a very important component of such a strategic approach to poverty reduction, in all cases specific policies targeting both rural and urban poverty were undertaken. This suggests a "growth plus..."(Weiss and Khan2006) strategy for development.

In addition to the nine sets of factors discussed above, there are also somewhat random, historically contingent factors.Khan's case study on Korea acknowledges the presence of such factors explicitly and reveals historically contingent events ranging from momentous events such as wars and revolutions to more usual changes in domestic and international political factors and changes in policies that depended on crucial personalities such as that of President Park in Korea in the 1960s.

What follows from the above identification of both the relatively necessary as well as the more contingent factors that have played a role is, I think, the need for taking a pragmatic and diagnostic approach to the problems of development and industrialization in the 21<sup>st</sup> century. It is necessary to identify distortions. It is also equally necessary to identify market failures and other institutional failures. Instead of taking a grand, presumptive approach to development, the role of a mix of heterodox policies with the willingness to revise policies before the cost gets too high seems to be the best recipe for avoiding failures. This has been the Korean experience including its response to the disastrous Asian Financial Crisis which in the Korean case was significantly affected by hasty financial market liberalization *inter alia*.<sup>8</sup>

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of a distributionally sensitive growth model for positive feedback loop innovation system(POLIS).

<sup>8</sup> Both the positive and negative experiences over time of Korean development suggests strongly a non-Washington consensus type pragmatic policies and institution building package geared to local history and culture for the LDCs in particular. For a fairly comprehensive analysis, see Khan(2009, 2011d).

In looking at institution building in the Korean case, it is also clear that generally, it is easier to list the functions that good institutions perform than it is to describe the shape they should take. In fact, consistent with the complexity approach outlined here, there may be a wide variety of institutions serving roughly the same function. From the Korean case, it is apparent that the desirable institutions provide a rough and ready type of security of property rights, enforceability of contracts and lead to a gradual and strategically conceived integration with the world economy. In addition, they also help maintain macroeconomic stability without a necessarily rigid conservative fiscal stance. Over time and given sufficient financial development, the state and private sector institutions should be able to manage risk-taking by financial intermediaries. In order to promote equitable growth there will also need to be institutions that can supply social insurance and safety nets, and create a democratic space for voice and accountability. But there is no one-size-that-fits-all for any of these functions.<sup>9</sup>

To sum up, the Korean case offers a set of concrete examples of the growth and development experiences during the post WWII period. Although no country can succeed by following mechanically the experience of another country, as outlined above, a number of helpful policy and institutional insights can still be drawn out from these cases. In the spirit of experimentation with rapid feedback and flexible policy making informed by a strategic medium to long run perspective, much can be done by the policy makers who are imaginative and pragmatic at the same time. Dynamic learning and flexible institution building are essential components of such a strategic approach to development. I now discuss the somewhat changed economic environment in the post cold war period and outline the need for some specific changes which Korea and other East Asian economies as well as BRICS can help bring about. This, in addition, to the lessons outlined above can be the most optimal way for Korea to help today's struggling developing economies.

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<sup>9</sup> See Chang (2007) for a number of thoughtful contributions on this topic among other things.

### **3. Conclusions---How Korean Model can be used today: Making Globalization Work towards Sustainable Industrialization and Development in the 21<sup>st</sup> century**

From the discussion so far it is clear that Korean development experience holds a number of lessons for other countries. From strategic openness to growth and innovation, there is much to learn from Korea. This is consistent with my nuanced position that for each developing country its own history and institutional specificities must also be taken into account. Also in keeping with my complex systems approach, perhaps the most significant areas in the Korean development experience to focus on are self-organization of both markets and government and their complex interactions with much social learning.

In addition to the positive lessons from the Korean experience and the willingness of Korea to extend aid and expertise to developing economies of Africa in particular, Korea can also play a much broader and significant role in the present turbulent global political economy. The critical discussion of both the Korean development experience and the financial and innovation systems in particular (Khan 2004a, 2010, 2011a,b,c) leads to two conclusions among other things. The first is that under the first phase of the US hegemony, frontline states like Korea benefited from an external environment that is no longer the same and will be impossible to replicate under the current rules of the game instituted by the US and other developed countries. Therefore, the current rules of globalization must change. The second conclusion is that even if these rules change and some other countries can move forward on the path of industrialization, the older 20<sup>th</sup> century modes of industrialization based on fossil fuel based technology will not be sustainable. As Khan(2009) demonstrates, even for Korea the current strategy of development and patterns of energy consumption are unsustainable. In this particular work reported in Khan(2009) , I have sketched the energy dilemma for Korea in this century. As long as the current geopolitical situation persists, the pursuit of present development strategy of Korea will further increase its energy dependence. For both political and economic reasons, Korea needs to rethink its development strategy. In my earlier work on Korean energy security I have sketched such an alternative strategy that relies much less on fossil fuels and emphasizes regional cooperation. Korean innovation system strategy also recognizes and strives for a more ecologically sound and socially inclusive system. Thus Korea can set a positive example here through both domestic practice and regional cooperation efforts.

Khan et. al.(forthcoming) shows this for the BRICS as a group also. This paper investigates the relation between rapid economic growth and environmental degradation in the BRIC economies. It utilizes environmental, macroeconomic and

financial variables coupled with Kyoto Protocol indicators based on panel data from 1992 to 2004. In keeping with the goal of examining long run sustainability, the long-run equilibrium relationship between economic growth and energy consumption is examined. *Feasible general least squares* procedure (FGLS) is employed to estimate the environmental degradation caused by increases in energy consumption. *Pooled regression analysis* is used to estimate the relationship between energy consumption and growth variables. The impact of excessive economic growth rates on energy consumption levels is studied by means of *threshold pooled ordinary least squares* (POLS) method. Moreover, this analysis takes into account the legitimate econometric criticism of the Environmental Kuznets Curve highlighted by Stern (2004). The findings reveal that higher energy consumption leads to increased CO<sub>2</sub> emissions in the countries under consideration. It is also found that rapid economic growth further inflates energy consumption levels in the emerging BRIC economies. The results of cointegration analyses also confirm these findings. Finally, the inclusion of the US and Japan as the world's largest energy consumers does not significantly alter the results of our study. Korea can also set an example for the larger BRIC economies and work with them towards an ecologically sustainable development strategy for all.

One of the most important changes in globalization must be the creation of a new global financial architecture that will play more of an enabling role than the current chaotic international financial system. Khan (2004b, 2011a,b) discussed this issue extensively and has suggested a hybrid type of structure. For the foreseeable future a hybrid financial architecture combining regional financial arrangements with a reformed IMF may be the best hope for global financial stability and development. In my work in this area, I have shown how IMF must and can change in a direction which allows for greater national policy autonomy for development. I have also shown that the IMF needs complementary regional institutions of cooperation in order to create a stabilizing hybrid global financial architecture that will be more democratic and pro-development in terms of its governance structure and behavior. Thus regional financial architectures will need to be integral parts of any new global financial architecture (GFA). The tentative steps taken towards regional cooperation in Asia since Asian financial crisis illustrate the opportunities and challenges posed by the need to evolve towards a *hybrid* GFA. Here Korea has learned much from its own experience and is playing a constructive and enabling role in the ASEAN+ 3 arrangements. Undoubtedly, in the future the economic diplomacy of Korea can help a great deal in moving the global and regional institutions towards a pro-development structure. This will be a truly visionary yet practical goal for Korean government in the international arena.

I would like to end by reminding us of the heroic sacrifices made by the Korean people for their freedom and prosperity. The great Korean poet Kim Chiha wrote from prison:

Oh! If a morning glory and sunbeam rested  
On my bright tear-brimming eyes  
That have through the dark night waited  
For the dawn with a gut-wrenching pain  
What a blessing it would be!

Thanks to the struggles of all the freedom-loving Koreans, the country has achieved both democracy and prosperity. If in the future Korea can effect a true synthesis of individual freedom with responsibility towards the larger community, it will not only have achieved the blessing that Kim's heartfelt poem mentions, but it will also set a tremendous example for rest of the world as well.

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## Appendix 1:

### **A ‘Simple’ Non-linear Model of Complexity, Growth, Distribution and Innovation System Motivated by the Korean Experience**

In order to give the reader some idea of the problem of formalizing complex technological systems motivated by the above case study of Korea in particular, we summarize here the basic structure of a ‘simple’ non-linear model embodying distinct technological systems which can be applied to analyze the technological trajectories in countries like Korea. At any single point in time, the model can be presented as a Social Accounting Matrix (SAM) representation of the socio-economic system. The key distinction here is the explicitly non-linear nature of the economy-wide functional relationships. The key theorem shows the existence of multiple equilibria. Some further considerations of complexity and increasing returns show that multiple equilibria are indeed the natural outcomes in such models. Thus, there would seem to be some role for domestic policy in guiding the economy to a particular equilibrium among many.

The virtue of an economy-wide approach to technology systems is the embodiment of various inter-sectoral linkages. In a SAM, such linkages are mappings from one set of accounts to another. In terms of technology systems, the production activities can be broken down into a production (sub-) system and a set of innovative activities. In practice, this presents considerable difficulties of classification and empirical estimation.

One major component of the entire innovation system is, of course, the expenditures on R&D. In the SAM for Korea used here, this can appear either as an aggregate expenditure along the column labeled R&D, or as a set of disaggregated expenditures.<sup>1</sup> In the latter case these may be specified according to productive activities (e.g., construction, electrical equipment, etc.) or by institutions (e.g., private R&D expenditures, government R&D expenditures, etc.). It should be emphasized that the dynamic effects of R&D on the economy can be captured only in a series of such SAMs over time. This approach is still at the conceptual stage, but appears to be quite appealing. One can contrast the possible policy experiments that can be undertaken within such a framework with the apparently ad hoc science and technology policies in many developing countries. In particular, the impact over time of many economic development policies including innovation policies can be traced by building and maintaining such SAMs.

Choice of new technology in a developing country is affected by research and development in at least three different ways. Such a country can attempt to develop new technology through R&D, as mentioned previously. This ultimately requires a positive feedback loop innovation system in order to be self-sustaining. Another alternative is to adapt existing technology. This too requires a production system geared towards innovation in a limited way. A third alternative is to import technology or to

acquire it through attracting foreign direct investment. In practice, all these different forms may be combined. The abstract model embodies all these different possibilities. However, the first option requires, among other things, a presence of multiple equilibria. In a unique equilibrium world the competitive equilibrium (under the assumption of complete markets) will always be the most efficient one. The presence of increasing returns usually destroys such competitive conditions.

We begin with a number of productive activities reflecting the existing technological structure. These activities are defined on the input-output subspace of the general and abstract mathematical space  $X$ . In addition to the values of inputs and outputs, points in this space could also represent household and other institutional income and expenditure accounts. We also incorporate the possibility of R&D as a separate productive activity. Formally, it is always possible to break R&D down into as many finite components as we want. The key relationship in this context is that between the endogenous accounts (usually, production activities and technologies, factors and households) and the exogenous ones. It is this relationship that is posited to be non-linear and this together with some assumptions on the relevant mathematical space can lead to the existence of multiple equilibria.

Although the existence theorems for these multisectoral models provide some structure for the equilibria as sequences of fixed points in the socio-economic structure with evolving technology systems, it is not specified a priori which equilibrium will be reached. The problem of equilibrium selection thus remains open. The idea behind a POLIS can now be stated somewhat more formally. It is to reach a sequence of equilibria so that in the non-linear models of the entire economy the maximal fixed points that are attainable are in fact reached through a combination of market forces and policy maneuvers over time. It is also to be understood that path-dependence of technology would rule out certain equilibria in the future. Thus initial choices of technologies can matter crucially at times.

### The Model on a Lattice

Define  $X$  as a vector lattice over a subring  $M$  of the real field  $R$ . Let  $x_+ = \{x \mid x \in X, x \geq 0\}$

A non-linear mapping  $N$  is defined such that  $N : X_+ \rightarrow X_+, N_0 = 0$ . Given a vector of exogenous variables  $d$ , the following non-linear mapping describes a simultaneous non-linear equations model of an economy,  $E$  :

$$x = Nx + d \tag{1}$$

for a given  $d \in X_+$ .

This non-linear system represents a socio-economic system of the type described previously. In order to specify the model further, the following assumptions are necessary.

1.  $X$  is order complete
2.  $N$  is an isotone mapping
3.  $\exists \hat{x} \in X_+$  such that  $\hat{x} \geq N\hat{x} + d$

In terms of the economics of the model, the non-linear mapping from the space of inputs to the space of the outputs allows for non-constant returns to scale and technical progress over time. The 3 assumptions are minimally necessary for the existence of equilibrium. Assumption 3, in particular ensures that there is some level of output vector which can be produced given the technical production conditions and demand structure.

Existence of Multiple Equilibria:

Theorem: Under the assumptions 1 - 3, there exists  $x^* \in X_+$  so that  $x^*$  is a solution of

$$x = Nx + d$$

Proof: Consider the interval  $[0, x] = \{\hat{x} \mid \hat{x} \in X_+, 0 \leq \hat{x} \leq x\}$  where  $\hat{x}$  is defined as in assumption 3. Take a mapping  $F$ .

$$F : x \in X_+ \rightarrow Nx + d$$

$F$  is isotone and maps  $[0, x]$  into itself.

Define a set  $D \equiv \{x \mid x \in [0, x], x \geq Fx\}$ .

By assumption 3,  $D$  is non-empty.

We now show  $x^* \equiv \inf D$  is a solution to  $x = Nx + d$ .  $x^* \equiv \inf D$ ; therefore  $x^* \leq x, \forall x \in D$ .  $F$  is isotone; therefore  $Fx^* \leq Fx \leq x$  for each  $x \in D$  implying.

$$Fx^* \leq x^*$$

From (2) we have  $F(Fx^*) \leq Fx^*$ . Thus  $Fx^* \in D$ ; hence  $x^* \equiv \inf D \leq Fx^*$  so,  $Fx^* \leq x^* \leq Fx^*$ . Therefore  $x^* = Fx^*$ .

This is an application of Tarski's and Birkhoff's theorem. The key feature to note here is that the equilibrium is not necessarily unique. It should also be noted that under additional assumptions on space  $X$  and the mapping  $N$  the computation of a fixed point can be done by standard methods (e.g. Ortega and Rheinboldt). A similar model can be constructed on Banach space as well.

Needless to say, any formalization of a complex system leaves out certain features. For example, the political features of POLIS are captured only indirectly and inferentially in the above model. But at least the ecological and distributive features can be captured by constructing the appropriate environmentally-sensitive SAMs and applying the model over time for a country like Korea. What the above verbal argument and formal exercise suggest is the feasibility of an alternative developmental model that builds upon some of the insights of the Asian success stories like Korea but also can take some necessary steps to face the ecological and political economic challenges of the 21<sup>st</sup> century.

## **Appendix 2: The Augmented National Innovation Systems approach and a more complex illustrative model**

## Multiple Equilibria on Banach Space for an Augmented National Innovation Systems model:

In this section the results for multiple equilibria presented verbally in the main text and formally in appendix 1 are further extended to functionals on Banach Space. We can define the model presented in appendix 1 again for monotone iterations, this time on a non-empty subset of an ordered Banach space  $X$ . The mapping  $f : X \rightarrow X$  is called compact if it is continuous and if  $f(x)$  is relatively compact. The map  $f$  is called completely continuous if  $f$  is continuous and maps bounded subsets of  $X$  into compact sets. Let  $X$  be a non-empty subset of some ordered set  $Y$ . A fixed point  $x$  of a map  $N : X \rightarrow X$  is called minimal (maximal) if every fixed point  $y$  of  $N$  in  $X$  satisfies

$$x \leq y (y \leq x)$$

Theorem: Let  $(E, P)$  be an ordered Banach space and let  $D$  be a subset of  $E$ . Suppose that  $f : D \rightarrow E$  is an increasing map which is compact on every order interval in  $D$ . If there exist  $y, \hat{y} \in D$  with  $y \leq \hat{y}$  such that  $y \leq f(y)$  and  $f(\hat{y}) \leq \hat{y}$ , then  $f$  has a minimal fixed point  $x$ . Moreover,  $x \leq y$  and  $x = \lim F^k(y)$ . That is, the minimal fixed point can be computed iteratively by means of the iteration scheme

$$\begin{aligned} x_0 &= y \\ x_{k+1} &= f(x_k) \quad k = 0, 1, 2, \dots \end{aligned}$$

Moreover, the sequence  $(x_k)$  is increasing.

Proof: Since  $f$  is increasing, the hypotheses imply that  $f$  maps the order interval  $[\bar{y}, y]$  into itself. Consequently, the sequence  $(x_k)$  is well-defined and, since it is contained in  $f[\bar{y}, y]$ , it is relatively compact. Hence it has at least one limit point. By induction, it is easily seen that the sequence  $(x_k)$  is increasing. This implies that it has exactly one limit point  $\bar{x}$  and that the whole sequence converges to  $\bar{x}$ . Since  $f$  is continuous,  $\bar{x}$  is a fixed point of  $f$ . If  $x$  is an arbitrary fixed point in  $D$  such that  $x \geq \bar{y}$ , then, by replacing  $y$  by  $x$  in the above argument, it follows that  $\bar{x} \leq x$ . Hence  $\bar{x}$  is the minimal fixed point of  $f$  in  $(\bar{y} + P) \cap D$ . It should be observed that we do not claim that there exists a minimal fixed point of  $f$  in  $D$ .

We can also show that if  $F : x \in X_+ \rightarrow Nx + d$  is an intersecting compact map in a non-empty order interval  $[x, \hat{x}]$  and  $x \leq Fx$  and  $F\hat{x} \leq \hat{x}$  then  $F$  has a minimal fixed point  $x^*$  and a maximal fixed point  $x^{**}$ . Moreover,  $x^* = \lim F^k(x)$  and  $x^{**} = \lim F^k(\hat{x})$ . The first of the above sequences is increasing and the second is decreasing.

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