Irreversibility, Sunk Costs, "News" and Evolutionary Economic Methodology

by

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N.B. All ideas are contestable, so that comments are most welcome. Not for citation without the permission of the author.

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Abstract

An enlarged conceptual framework for understanding **systemic** adjustment processes in economics highlights the impact of news on agents' reoptimized behavior and strategic interdependencies in the presence of market imperfections. Unforeseen contingencies redefine the systemic option value of existing and prospective irreversibilities by determining the degree of recuperability of existing investments, while also generating divergencies between revised market values and private returns to holding assets. State dependent, or endogenous, sunk cost evaluations, in turn, depend on simultaneous market entry, exit, and reinvestment decisions. The anatomy of strategic interactions between agents, following their internalization of news, along with associated adjustment processes, is shown to be defined by realized and potential sunk costs. Associated pecuniary historical externalitities, which capture key channels by which history conditions the evolution of economic systems, as well as the interrelation between market and non-market decisions. The distinction between *ex ante* sunk costs, contingent on agents' initial information spaces, fixed costs and *ex post* or *endogenous* sunk costs points to their critical role as building-blocks for modeling evolutionary economic processes. Paradoxically, sunk costs can entail quite divergent implications for the decisions of individual agents and for the evolution of economic systems, as a whole.

An examination of the interrelation between information revelation, the hold-up and the lock-in problems, highlights the endogeneity of sunk cost evaluations, as well as how agents' decision trees are redefined in response to news. A subsequent extension of Owen and Ulph (2002) focuses on the systemic impact of an unanticipated integration shock, hence "pure news", on endogenous market entry and exit in a framework of international oligopoly. A unique correspondence between alternative trade regimes and different configurations of sunk and fixed costs points to a central identification issue in economic modeling. Specifically, in scenarios of market imperfections and strategic interdependence, the historical evolution of an economic system is defined by the interface between existing and newly incurred sunk costs, which also correspond to asymmetric choice sets and optimization problems across agents. Generic implications of the analysis include a defining role for endogenous sunk costs in explaining micro-foundations of evolutive learning processes and commitment, expectations formation, new branches in game-theoretic decision trees and the economics of time.

***JEL classification codes*: B4, D8, F1, L1**

***Key words*: irreversibility, sunk costs, information revelation, economic integration, identification, evolutionary economics, methodology**

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Can One Expect the Unexpected?

Thinking about the Unthinkable.

Or, without a Fundamentally Different Conceptualization of Sunk Costs, Is Existing Economic Methodology Completely Complete?

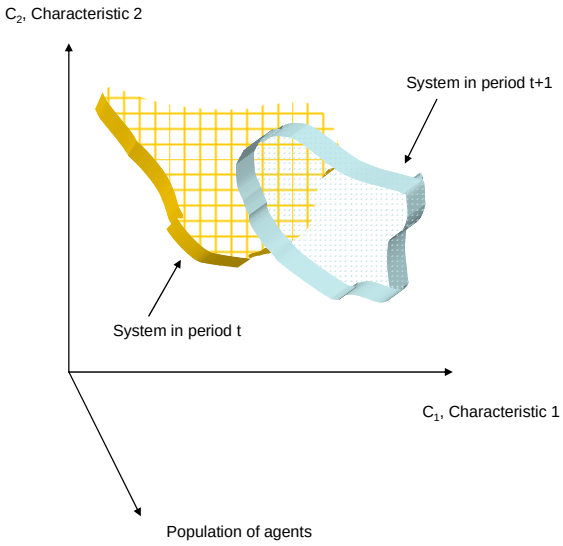
I. Introduction

Irreversibility is an essential mechanism by which history defines certain critical dimensions of economic analysis. Since time inevitably marches on, the salient features of economic systems can be uniquely determined in given periods by specific constellations of economic agents and institutions, along with their characteristics, unique interactions and environments. The past decisions of individuals and societies, as well as historical market evaluations, can, in turn, define current and future optimization processes. Such mechanisms thereby generate specific path dependencies, which uniquely capture the evolution of economic systems.

In order to validly determine a system's trajectory, it is necessary to consider the interrelations between all of its constituent parts over time, as well as any forces and mechanisms that can potentially impact adjustment processes. The latter include factors that determine how populations of agents and their characteristics change over time, as illustrated for a generic case in Figure 1. More specifically, the evolution of economic systems is potentially impacted by the diffusion of newly released information in a system as a whole, subsets of agents becoming better informed, as well as by these and other mechanisms which account for the endogenous exiting and entry of agents.

Figure 1:

Representation of an Evolutionary Economic System



In existing economic analysis, certain aspects of irreversibility are captured by the notion of sunk costs. In general, this concept can be understood to represent the portion of the historical value of an initial investment that is considered to be irrecuperable, at a given point of time. Yet, neither the possible evolution of sunk cost evaluations over time, nor the factors accounting for such changes or associated implications are highlighted in most existing economic analysis. Indeed, most major graduate microeconomic and macroeconomic textbooks make only fleeting reference to sunk costs.[1] Such an omission appears to discount the significance of any vital role for sunk costs in accounting for evolutionary processes, general equilibrium analysis, macroeconomics and a wide range of other, modeling frameworks. Furthermore, only cursory, and often divergent, treatments of this concept are typically proposed in many introductory and intermediate microeconomic and/or macroeconomic textbooks.[2] On the one hand, one approach to the treatment of sunk costs is represented by the idea: "Let bygones be bygones."[3] Often it is explicitly stated, or implied, that such sunk cost evaluations are exogenous, and, as such, do not play any critical role in either the objective functions defining individual agents' optimization decisions over time, or their strategic interactions. From such an *ex post* perspective, the basic argument appears to be that, since sunk costs reflect past commitments, their values and characteristics are irrelevant for subsequent optimization processes. Furthermore, when a specific value for a sunk cost is attributed for an agent's *ex ante* optimization problem, as in the case of a representative firm's market entry and exit decision, it is either explicitly or implicitly suggested that the same sunk cost value applies. Such approaches, in effect, compress time, while invoking a strong rationality assumption that ostensibly precludes any states of nature such that the indicated value would change over a given time horizon due to unforeseen contingencies. Hence, existing textbook treatments of sunk costs reflect a rather ahistorical role for sunk costs, whereby the irreversibilities, stemming from past investments and commitments, have already been fully internalized by agents and are irrelevant for their optimal choices. This eschews a recognition that that the evaluation of sunk costs is potentially variable and dependent on future states of nature, since the extent of irrecuperability is linked to market reentry in order to sell off an asset at its residual spot value. Moreover, either explicitly or implicitly, existing approaches convey the misleading impression that sunk costs do not influence future economic decisions and the associated trajectories of economic systems.

Admittedly, the role of sunk costs in defining market entry, contestability and industrial structures is clearly recognized in the industrial organization literature, which includes, notably, the seminal work of Baumol, Panzer and Willig (1982) and Sutton (1991). Their research, along with other contributions relating to sunk costs, is synthesized in intermediate and advanced textbook expositions, such as those by Cabral

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[1] In this regard, see Kreps (1990), Mas-Colell, Whinston and Green (1995), along with Varian (1992).

[2] Representative treatments include those of Baumol and Blinder (2001), Case and Fair (1999), Frank (2003), Katz and Rosen (1994), Mankiw (2001), Nicholson (1998), Samuelson and Nordhaus (1998), Stiglitz and Walsh (2002), Pindyck and Rubinfeld (2001), and Varian (1992, 2003). Certain of these are critiqued in Section II.

[3] This terminology is explicitly used, for example, by Mankiw (2001; p. 298), who goes on to suggest that: "Because nothing can be done about sunk costs, you can ignore them when making decisions about various aspects of life, including business strategy" (p. 299).

(2000), Martin (1993), Shy (1995) and Tirole (1988). However, the prevailing approaches focus on *ex ante* interpretations of sunk costs, which highlight the potential impact of anticipated irreversibilities on individual agents' current optimal choices. For example, firms' market entry, advertising, and R&D decisions are examined, under the underlying premise that agents either face known market conditions determining the evaluation of sunk costs, or given probability distributions representing their values. The subsequent reformulation of agents' decisions in light of the *ex post* revelation of information and unforeseen contingencies, or, alternatively, "news", is not, typically, central to that analysis.

In their analysis of the optimal timing of investment options, Dixit and Pindyck (1994) have considered certain implications of uncertainty for the analysis of sunk costs. In their real option approach, forward-looking representative agents are, in effect, understood to optimally internalize the "call" option value of future sunk cost commitments, while facing known ex ante probabilities of the sunk cost evaluations. An implicit feature is that the interrelation between uncertainty and sunk costs is fully internalized by agents in their *ex ante* optimal decisions, so that the impact of information revelation in defining the outcome of strategic interactions, at a systemic level, is not considered. As such, their analysis does not allow for eventual ramifications of "news" for the *ex post* reoptimization of individual agents' decisions, and the resulting endogenous revaluation of the irreversibilities, represented by investments and associated sunk costs, in general equilibrium.

Stated differently, the existing analysis of sunk costs and investments under uncertainty does not consider the consequences of unforeseen contingencies for the open option value of irreversible commitments in general equilibrium.[4] Thus, there is a need to examine how existing sets of investment values are impacted by different forms of "news", at the time information is revealed, and how such changed spot revaluations are interrelated with economic agents' optimal behavior and strategic interactions. In this regard there needs to be an explicit analysis of the interplay between the ex ante and ex post evaluations of the sunk costs.

In the expanded framework proposed here, sunk costs can be understood to embody dimensions of both *ex ante* commitments and the endogenous *ex post* evaluation of those commitments, along with how the interrelation between eventual decommitment and recommitment is defined by information revelation at a systemic level. Notably, these issues are of particular portent and complexity in the presence of heterogeneous characteristics and information sets across economic agents, as well as different historical investment patterns. Thus, the reconfiguration of agents' information sets, following the revelation of partially, or fully, unforeseen contingencies, may result in the reoptimization of their decisions.[5] Indeed, what might be coined the "economics of mistakes", corresponding to ex post reevaluations of existing irreversibilities, is reflected in the endogenous determination of sunk costs. These can be critical for understanding

[4] While it is often convenient to consider the proposed analysis of sunk costs in terms of investment theory, it is apparent that the analysis applies with equal validity to a more general analysis of commitment, so that these terminologies will be used interchangeably.

[5] From the standpoint of specific agents, unforeseen events can arise from a variety of economic shocks, including, for example, technological breakthroughs, changes in macroeconomic environments or natural phenomena, and are also linked to the newly revealed strategies of other agents. One subset of such cases arises under asymmetric information, when previously uninformed agents gain access to new information.

entry, exit, and other performance decisions of economic agents, along with the associated evolution of economic systems in general equilibrium.

The purpose of this paper then is to propose an enlarged conceptual framework for understanding sunk costs and their ramifications, while identifying generic implications for economic analysis. More specifically, the state and time dependency of sunk cost evaluations, along with their interrelation to associated variations in the returns to past investments and commitments, is highlighted. Sunk costs are understood here to correspond to the irrecuperable part of the historical market value of an earlier investment or commitment, at a given subsequent point of time.[6] The sunk cost corresponds to the discrepancy between the historic value of the investment, which is inherently irreversibility, and the maximum of the subsequent spot evaluations for either its residual market value, or the discounted present value of the returns to that investment.[7] [8] Crucially, the latter may entail private information. Hence, the extent of sunkedness can vary over time, depending on how the revaluation of the existing irreversibility is defined by the liquidity of markets for that asset or commitment, associated transactions costs for its resale, along with eventual discrepancies between such market evaluations and the returns to the committed agents. The evaluation of sunk costs are of particular relevance to economic analysis, when existing commitments "bite", in the sense that new information is revealed and there are associated consequences for the reoptimization of agents' decisions. A consideration of the reactualized value of existing commitments, relative to the consequences of decommitment, serves to capture a critical channel by which history accounts for the dynamic evolution of economic systems.

A crucial distinction is made here between, on the one hand, *ex ante* sunk costs and, on the other hand, *ex post* or *de facto* sunk costs. *Ex ante* sunk costs are based on either foreseen states of nature, or anticipated probability distributions, along with known scenarios regarding strategic interactions with other agents. Unlike fixed costs, the irreversibilities embodied in *ex ante* sunk costs generate exit costs, if agents leave markets. As such, they capture effects of irreversibilities, which are, at least to some degree, already internalized in individual agents' optimal decisions and are exogenously specified within a given time and economic framework. It is this forward-looking specification for sunk costs, which currently prevails in most economic analysis.

In contrast, economic values linked to the irreversibilities embodied in *ex post* or *de facto* sunk costs can be crucially defined, in general equilibrium, by the impact of partially, or wholly, unforeseen contingencies. This distinctive category of sunk costs could alternatively be termed "*sunk costs with endogenous effects*". A critical insight is that, when there are partially, or completely, unforeseen contingencies, economic agents

[6] Although the terminology, "sunk costs", implies losses, changes in value, linked to irreversible decisions, can clearly be positive as well. It is decisions in time and historical values of investments at specific times in the past, rather than their subsequent values, which are fundamentally irreversible. Furthermore, relative to initial evaluations, the residual values of investments, or other commitments, clearly have variably evaluations at different points in time. In this sense, "sunkedness" is inherently a question of degree.

[7] This residual market value of an investment might also be termed its scrap value. However, such terminology might be misleading since such an evaluation may be determined by the specific way in which characteristics are bundled.

[8] In effect, sunk costs can be viewed as constituting a form of double irreversibility, since neither the original historical commitment to the investment, nor its initial asset value, can be ignored.

will potentially reoptimize their earlier decisions, thereby internalizing such "news".[9] This leads to an associated endogenous determination, in general equilibrium, of the economic values linked to sunk costs. In this process, different initial irreversibilities across agents can generate pecuniary externalities which can define the impact if sunk costs and associated investment returns. Furthermore, the present discounted evaluations, by individual agents, of the residual value of initial investments can diverge from market values due to various factors, including, notably, transaction costs. Thus, the initial investment or commitment can be regarded as an open option value, which has associated revaluation that is "called" by "news". Analogously, whenever agents make commitments, there is the associated possibility of revaluations of not only those commitments, but also the opportunity costs of decommitment and recommitment. These effects need to be simultaneously considered in a complete theory of economic systems, wherein the *ex ante* and *ex post* evaluation of sunk costs embodies the duality between such commitment and decommitment. Finally, it is argued that the impact of unforeseen contingencies on the evaluation of sunk costs can be crucial for correctly identifying alternative structural economic models, and in accounting for the nature of distinctive hysteresis effects in the dynamic evolution of economic equilibria. Thus, the distinction between *ex ante* and *ex post* sunk costs points to a central identification problem in economic analysis.

An expanded taxonomy for understanding sunk costs is proposed here, which recognizes the state and time contingency of sunk cost evaluations. The present research initially offers an extension of analysis proposed in Owen and Ulph (2002), by examining a further model simulation and extended interpretation of associated findings. The framework for that analysis is a two-country oligopolistic model, which links configurations of fixed and sunk costs to distinctive sets of ex post equilibria, following an unanticipated integration shock. Since firms initially assign a zero probability to an event, which is then actually realized, the unanticipated reduction of variable trade costs corresponds, in terms of expectations, to a "big bang" event. As such, the integration shock constitutes a form of "pure news". Endogenous industrial structures arise due to firms' entry and exit from the two markets. More specifically, it is shown that there is an unique mapping from constellations of fixed and sunk costs to three different trade regimes. These correspond to traditional trade theory, "new" trade theory, and a distinctive market access regime. The latter scenario, which had not previously been identified, highlights a scenario where there is an *ex post* evaluation of irreversibilities entailing market exit costs. A specific set of such sunk costs, linked to establishing market access, plays a dominant role in accounting for these equilibria, relative to other *ex ante* fixed and sunk cost commitments. In comparison, the "new" trade theory is a regime where fixed costs, again linked to obtaining market access, have a preponderant influence. These fixed costs capture lumpy irreversible expenditures within a given time period, which are internalized in the firms' beginning-of-period decisions. Finally, the equilibria corresponding to traditional theory are those where neither fixed, nor sunk, costs of market access are relatively important, when compared to other *ex ante* cost commitments.

[9] Learning and search processes inherently, also, engender sunk investment costs with both *ex ante* and *ex post* characteristics.

It is contended here that the distinctive trade regimes actually suggest a central identification problem in economics; wherein distinctive categories of sunk costs can critically define alternative structural economic models, associated reduced form solutions and welfare changes, following economic shocks. Indeed, it is crucial to recognize both the potential impact of partially, or completely, unforeseen contingencies, along with the associated revelation of information, on agents' decisions and strategic interactions, in light of the extent of existing ex ante irreversibilities over given time periods. An application of the analysis is to understanding how the efficacy of economic policies can critically depend on not only the extent that they are foreseen, and already internalized in agents' intertemporal decisions, but also degrees of commitment, as reflected by evaluations of *ex post* sunk costs. This latter observation suggests microfoundations of debates regarding adaptive and rational expectations.

The organization of the rest of this paper is as follows. Section II offers a brief overview and critique of representative textbook, and other, treatments of sunk costs. It is contended that existing specifications for sunk costs have not validly characterized the interrelation between irreversibilities, changes in residual market evaluations of initial investments, and evolutionary economic processes. In this latter regard, unforeseen contingencies and information relevation, or news, can lead to a crucial distinction between *ex ante* and *ex post* evaluations of sunk costs, while also suggesting a potential paradox regarding the divergent roles of sunk costs in partial and general equilibrium. In Section III the interrelation between sunk cost evaluations and the extent of recuperability of irreversible investments is initially analyzed, more formally, in the context of the relation between the hold-up and lock-in problems, as illustrated by labor markets with, alternatively, firm-specific and generic human capital. The analysis highlights both the endogeneity of sunk cost evaluations to news, and the implications of unforeseen contingencies for redefining a representative agent's decision branches. Specifically, inequality conditions then characterize whether, or not, the agent should sell off an asset holding. Section IV proposes an analysis, which extends the research of Owen and Ulph (2002) by focusing on the systemic impact of an unanticipated integration shock. In a framework of international oligopoly, "pure news", generates endogenous market entry and exit, leading to a central identification issue in economic modeling. This applies to scenarios with market imperfections and strategic interdependence between agents, as shown by a unique correspondence between alternative trade regimes and configurations of different sunk and fixed costs. Asymmetries between the choice sets and optimization problems of agents are defined by existing and newly incurred endogenous sunk costs. Once the impact of unforeseen contingencies is recognized, a category of sunk costs can be identified, which have distinctive hysteresis effects and other implications, relative to those of either fixed costs or *ex ante* sunk costs. The impact of *ex post* or *de facto* sunk cost evaluations is critically dependent on the interrelation between incumbent agents with existing irreversibilities and those incurring new irreversibilities. Agents are understood to reformulate their optimal decisions in light of the specific nature of unforeseen contingencies and the related *ex post* evaluation of *ex ante* investments/commitments. Based on this analysis, Section V then proposes a new taxonomy for understanding sunk costs and the interrelation between market and non-market activity, along with associated market adjustment processes. The interrelation between fixed costs, sunk costs and news if also clarified by characterizing the branches

for an agent's *ex post* entry and exit decisions. In Section VI, a range of applications of the analysis is also suggested. These include the micro-foundations of debates regarding the determinants of expectations and learning mechanisms, endogenous preferences, new branches in decision tress in game theory and the economics of time. The principal insights of the paper are then summarized in a concluding section and directions for further research are proposed.

II. An Overview of Existing Interpretations of Sunk Costs

A striking feature of existing textbook, and other, discussions of sunk costs is an apparent lack of consensus regarding an appropriate definition for this concept.[10] One representative, pedagogical treatment of sunk costs is provided in the intermediate microeconomic theory textbook by Nicholson (2005). There the notion is principally developed in the context of firms' *ex ante* "commitments" to investment and market entry. Specifically, Nicholson defines sunk costs in the following terms:

"one-time investments that must be made in order to enter a market. Such investments allow the firm to produce in the market but have no residual value if the firm exits the market". p. 458

This discussion is rather restrictive, since it ignores the issue of possible implications of a potential loss in value for such investments, over specific time periods, even when the firm remains in the market. A related issue concerns the need to consider determinants of the residual value of such investments, as well as how unanticipated changes in a firm's economic environment they impact its strategic decisions and performance. Furthermore, this and other treatments appear to view sunk costs as being confined to the analysis of industrial organization, and to suggest, misleadingly, that the evaluation of the sunk costs is necessarily identical at the time of a firm's entry and exit. Indeed, many treatments of sunk costs appear to be singularly atemporal. Moreover, the somewhat exclusive emphasis on a firm's market entry decisions seems to suggest that the concept is not of relevance to understanding other features of both individual and systemic economic performance. Crucially, how sunk cost evaluations might evolve endogenously over time, as a function of unforeseen contingencies, is not considered. The anticipatory specification for the role of sunk costs is also reflected in the definition proposed by Walsh and Stiglitz (2002), who consider sunk costs to arise if "..an expenditure has already been made and cannot be recovered no matter what choice is made, a rational person would ignore it." p. 37 This characterization also seems to equate the non-recuperable nature of sunk costs with the suggestion that the sunk costs do not influence an agent's subsequent decisions, regardless of the evolution in their value over time. An implicit implication of their analysis is a strong rationality assumption that agents can anticipate all relevant states of nature, and thereby preclude any state where changes in

[10] Collectively, the divergent characterizations of sunk cost generate a rather impressionistic formulation of this concept.

the degree of irrecuperability, reflected in sunk cost evaluations, might influence agents' subsequent decisions.

Alternatively, there is the definition proposed by Pindyck and Rubinfeld (2001), as reflected by the following two excerpts:[11]

"Although an opportunity cost is often hidden, it should be taken into account when making economic decisions. Just the opposite is true of a **sunk cost**: an expenditure that has been made and cannot be recovered. A sunk cost is usually visible, but after it has been incurred, it should always be ignored when making future economic decisions.

Because a sunk cost cannot be recovered, it should not influence the firm's decisions. For example, consider the purchase of….The expenditure on this equipment is a sunk cost. *Because it has no alternative use, its opportunity cost is zero.* Thus it should not be included as part of the firm's costs. The decision to buy equipment may have been good or bad. It doesn't matter. It's water under the bridge and shouldn't affect current decisions." p. 205

"Now consider a *prospective* sunk cost. Suppose, for example, that the firm has not yet bought the specialized equipment but is merely considering whether to do so. A prospective sunk cost is an *investment*. Here the firm must decide whether that investment in specialized equipment is *economical* – i.e., whether it will lead to a flow of revenues large enough to justify its cost." p. 205

Note that this last paragraph highlights the idea that it is possible to envisage future investment decisions in an essentially atemporal context, where lags from immediate, or earlier, economic shocks are ignored. In much of the associated discussion, there is an implicit, if not explicit, understanding that sunk costs are fully known *ex ante* by agents, who are able to integrate such sunk costs in their optimization behavior. This constitutes a strong rationality assumption in terms of agents' ability to understand future economic processes and precludes a role for unanticipated events, arising from a wide class of exogenous shocks. Indeed, it will be contended that the artificial partitioning of sunk costs in *ex ante* and *ex post* terms, as set out in basic textbooks, obfuscates what may be one of the most neglected issues in economics. Thus, it will be maintained that sunk costs can be associated with important invisibilities across agents, due to the asymmetric partitioning of information spaces, or, alternatively, informational failures.

In the industrial organization literature, Baumol, Panzer, and Willig (1982) and Sutton (1991) have examined the role of sunk costs as investments, which can explain market contestability and industrial structures. Further advanced treatments of investment and capacity issues related to sunk costs have been explored by Dixit and Pindyck (1994). More specifically, the latter authors examine irreversible investment under uncertainty and analyze the interrelation between such decisions and option pricing. Nonetheless, the explicit treatment of sunk costs, defined in one way or another, is conspicuously absent from many other areas of economics, including, notably, most general equilibrium and macroeconomic modeling exercises. Furthermore, there appears

[11] See, alternatively, Varian (2003) for an alternative treatment, as well as, Frank (2003) and Mankiw (2001), among others, for comparable discussions at more introductory levels.

to be a starkingly ambiguous treatment of sunk costs as alternatively *ex post* and *ex ante* notions, in different contexts, without adequate attention to the underlying dynamic processes, which might generate sunk costs. Notably, the expectational dimension of the determination of sunk costs, when there are unforeseen contingencies, is conspicuously absent from most existing analysis.

Contrary to prevailing approaches to the treatment of sunk costs, which are reflected by the foregoing representative treatments, it is maintained here that sunk costs can be associated with important invisibilities across agents, due to the asymmetric partitioning of information spaces. As such, the evaluation of sunk costs often entail informational market failures. Furthermore, it will be contended that the determination of past sunk costs can be critical for the understanding "future economic decisions" in a general equilibrium framework, where the strategic decisions of agents are impacted by "news". In this regard, a critical distinction needs to be made between, on the one hand, the extent of irreversibilities in the value of initial investments and, on the other hand, the stream of returns generated by such sunk cost investments. More specifically, this paper will distinguish between, on the one hand, *ex ante* sunk costs and, on the other hand, *ex post* or *de facto* sunk costs, which are impacted by, at least partially, unforeseen contingencies or "news". The latter can also be termed as *sunk costs with endogenous effects*.

III. Sunk Costs, Labor Markets and "News": Hold-up versus Lock-in

The potential endogeneity of sunk costs to "news" can be highlighted by examining the impact of unforeseen contingencies on the *ex post* evaluation of an asset. In particular, it will be shown that the extent of recuperability of the initial investment can critically determine agents' reoptimization decisions and whether, or not, to sell off the asset. The analysis here focuses on specific labor market examples, which differ in terms of the interrelation between the degree of specificity of human capital and the *ex ante* incidence of its financing.[12] A key initial insight is that *ex post* configurations of sunk costs, linked to *ex ante* investments in firm-specific human capital, are critically defined by the extent of unanticipated demand shocks. Crucially, such a human capital investment entails a hidden *ex ante* hold-up problem, which is revealed by the specific unforeseen contingency that generates an associated *ex post* lock-in effect. When human capital is firm-specific and the costs of skill formation are borne either by firms or workers, the endogenous value of sunk costs are reflected by inequality conditions. These determine whether firms retain skilled workers, even though the *ex post* marginal product of their continued employment falls short of the *ex ante* financing cost for their training.

[12] The proposed analysis here offers, in certain respect, a more general paradigm to that considered by Fukuda and Owen (2005). The latter explored how sunk costs can explain certain unique features of Japanese labor markets and, thereby, account for a pronounced macroeconomic slowdown in Japan during the 1990s and associated hysteresis effects. ….. The analysis thereby offers a more general paradigm to that of Fukuda and Owen (2005), which has explored how sunk costs can explain certain unique features of Japanese labor markets and, thereby, account for the pronounced macroeconomic slowdown in Japan during the 1990s. ….. Fukuda and Owen (1994) demonstrate that unskilled workers bear a disproportionately large brunt of an initial unforeseen macroeconomic shock.

The combined role of the hold-up problem and lock-in effect can define both the endogeneity of sunk costs to news and their *ex post* evaluation. This argument can be further developed on the basis of Figures 2 through 4. The *ex ante* determination of a representative firm's optimal decisions for hiring and investing in human capital formation are illustrated in Figure 2. In this initial scenario the firm is assumed to know with certainty the demand for its products and, hence, the downward sloping gross marginal value product (MVPs) of the skilled workers. The shaded rectangle, reflecting the training costs, is defined by the number of skilled workers hired, N_t^S, and the training costs per worker, h, which correspond to the vertical distance of the rectangle. In the Japanese system of life-long employment, the standard investment hold-up problem, is resolved by the life-time seniority labor contracts.[13] Thus, firms have traditionally been prepared to absorb all of the training cost, since they are assured of receiving the full returns to that human capital investment. The corresponding salary paid out to the skilled workers amounts to w_t^S. Critically, the *ex ante* optimal employment decisions of the firm are characterized by a standard condition, which in its simplist version is given by:

$$(1) \quad w_t^S + h = MVP$$

More generally, the unit cost of human capital formation, h, can be either financed by the firm and/or by individuals, where the variable ϕ, defined over [0,1], represents, the share of those expenditures borne by the firm. Hence, 1 - ϕ constitutes denote the portion of h incurred by workers. The human capital formation can also be of either a generic nature or firm-specific. The sympol μ represents the share of h which is of a generic nature, such that it can be readily transferred to other labor markets. As an initial simplification, it can be assumed that firms are only willing to finance firm-specific human capital. In light of the foregoing notation, the general form of the *ex ante* optimization problem for the firm in period t is given by:

$$(2) \quad \text{Max } \pi_t = P_t(Q_t(N_t^S))Q_t(N_t^S) - (w_t^S(N_t^S) + \phi(1-\mu)h)N_t^S$$
$$\text{w.r.t. } N_t^S$$

Note that firms are making two interdependent *ex ante* commitments in period t. In light of their preparedness to finance a certain proportion, ϕ, of firm-specific human capital, $(1-\mu)h$, they determine their optimal hiring levels N_t^S. Hence, from the firm's perspective, the *ex ante* gross expenditures, v_t^S, per unit of labor hired in period t, are given by:

$$v_t^S = w_t^S(N_t^S) + \phi(1-\mu)h .$$

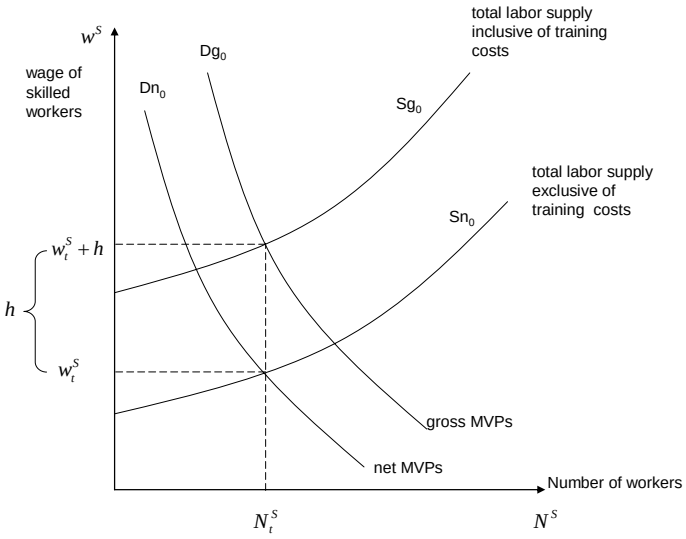
When it is assumed that the wage rate does not depend on the firm's level of hiring, the generic form of the reduced form solution for the optimal level of hiring is given by:

[13] Tirole (1988) offers a general overview of the hold-up problem.

$N_t^S = f(w_t^S, \phi, \mu, h)$ where $f_1 < 0,\ f_2 > 0,\ f_3 < 0, f_4 < 0$

Figure 2

Ex Ante Analysis of Labor Market Equilibrium with Human Capital Formation



w_t^S : wage rate for skilled workers, when training costs are borne by firms

N_t^S : number of skilled workers hired *ex ante* in period t

h : costs per worker of training

$MVPs$: marginal value of product of skilled workers

▨ : *ex ante* training costs

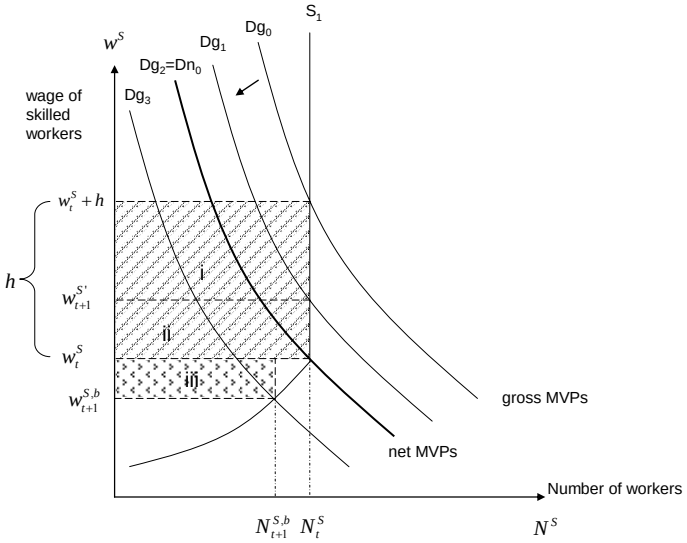
The *ex post* analysis of labor market equilibrium, depicted in Figures 3a through 3c, is contingent on the extent of the unanticipated macroeconomic shock, which is illustrated by leftward shifts for alternative gross MVPs schedules. In the initial of these figures, 3a, there are two different sub-regimes, which are defined by the extent of those shifts relative to the original net MVPs schedule. A first adjustment process can be defined when the firms are willing to retain their skilled workers at the original level of N_t^S. This scenario, which would arise so long as there are sufficiently high firing costs, and the shortfall in product demand does not surpass the net MVPs for the skilled workers. This explains the vertical section of the labor supply schedule, L^S. Hence, the evaluation of the sunk cost loss incurred by a representative firm, which is endogenous to the specific nature of the news, is crucially determined by the intersection of the post-shock gross MVPs schedule and the vertical part of the L^S curve.[14] This endogenous sunk cost value corresponds, then, to an *ex post* revelation of the hidden hold-up problem, which can be termed a "lock-in effect". It arises from the historical irreversibility of the firms' initial hiring and human capital investment commitments. The evaluation of the extent of the sunk cost is determined by the interaction between the configuration of these commitments and the specific nature of the unforeseen contingency. As elaborated further in the next section, such news can be though of as "calling" the option value of those *ex ante* commitments.[15] "Graphically, the *ex post* evaluation of the sunk cost corresponds to a rectangle, which is a subset of the original training cost rectangle in Figure 2. However, when the size of the unanticipated shock is sufficiently large to generate a shift in the gross MVPs below the intersection between L^S and the net MVPs schedule, the firms suffer a sunk cost losses, which are at least as large as the original training costs. In this second sub-regime, firms will seek to fire, at least some, of their skilled workers.

[14] Fukuda and Owen (2004) analyze how alternative evaluations of such sunk costs correspond to distinctive hysteresis effects. These are shown to magnify the effects of an initial macroeconomic shock and permanently lower firms' overall skill formation.

[15] While the case of a macroeconomic slowdown is highlighted in this example, it is apparent that a variety of other unexpected changes could generate a range of sunk costs. For example, an unexpected technological change could, by impacting the returns to earlier human capital investments, define the incentive that a firm has to hold on to older workers, rather than train new ones.

Figure 3a

Ex Post Analysis of Labor Market Equilibrium



w_t^S : wage rate for skilled workers, when training costs are borne by firms

$w_{t+1}^{S'}$: wage rate for skilled workers, following a macroeconomic shock in period t+1

$w_{t+1}^{S,b}$: bargaining wage rate for skilled workers in period t+1

N_t^S : number of skilled workers hired *ex ante* in period t

$N_{t+1}^{S,b}$: number of skilled workers kept in period t+1 under bargaining solution

h : costs per worker of training

$MVPs$: marginal value of product of skilled workers

i + ii : *ex ante* training costs

iii : lost wages under bargaining

A critical insight to emerge from the foregoing analysis is that the *ex post* evaluation of the sunk cost can differ from the *ex ante* evaluation, depending on the nature of the unanticipated shock. Hence, the sunk cost is a state-dependent evaluation, which depends on the nature of the unforeseen contingency. Let us also define a parameter λ_t, such that $\lambda_t \in [0, 1]$. This parameter captures the share of the initial value of the investment, I_0, which is considered to be non-recuperable at the period, t, following the revelation of new information. Hence, this *ex post* evaluation of the sunk cost is given by:

$$(4) \quad SC_t = \lambda_t I_0$$

In this particular example, where human capital is firm-specific, and, as such, not transferable between agents and has no exchange value on outside markets, the value of sunk costs also corresponds to a discrepancy between an *ex ante* understanding of the extent of a hold-up problem (if any) and its *ex post* realization, as manifest in a lock-in effect. Notably, unforeseen contingencies can result in lock-in effects without there being any perceived hold-up problem, initially. If it were possible to "rewind the hands of time", it would be recognized that there was actually, *ex ante*, a hidden hold-up problem, which generated the lock-in effect.

Nonetheless, as is conveyed in Figures 3b and 3c, determining the final equilibrium and distribution of sunk costs is potentially more complex than in the foregoing scenarios. The unforeseen contingency can potentially generate a wage-bargaining game with endogenously created, asymmetric decision branches for the representative firm and workers. More specifically, the firm faces a new decision tree following the realization of an unanticipated state of nature, provided it at least shares the propriety right for the firm-specific, human capital asset. In particular, the historical commitment to hold that asset will be potentially renewed or reversed, depending on the following inequality conditions

$$(5a) \quad w_t^S < MVP$$
$$(5b) \quad w_t^S > MVP$$

Furthermore, as shown in Figure 3b, the optimal *ex post* asset holding of the firm entails a tradeoff. More specifically, this *ex post* tradeoff is illustrated, for a scenario where it was the firm that financed the *ex ante* human capital investment. Given the downward sloping curve for the skilled workers, there is an interdependence between the asset returns associated with retaining workers and the lost revenues from firing workers. This tradeoff is represented, respectively, by the rectangles A and B, which reflect a relatively standard optimal demand elasticity condition, which also depends on the *ex post* value of wages. Whereas when the firm fires workers it loses associated sunk costs, represented by B, but thereby increases the net returns for the retained workers, as reflected by the reduced size of the sunk cost losses, represented by the rectangle A. The firm's *ex post* optimization problem involves maximizing the revenues of retained works, without considering the initial value of the sunk cost investment, which is a "bygone" in

this second stage re-optimization problem. The *ex post* re-optimization problem of the firm is given by:

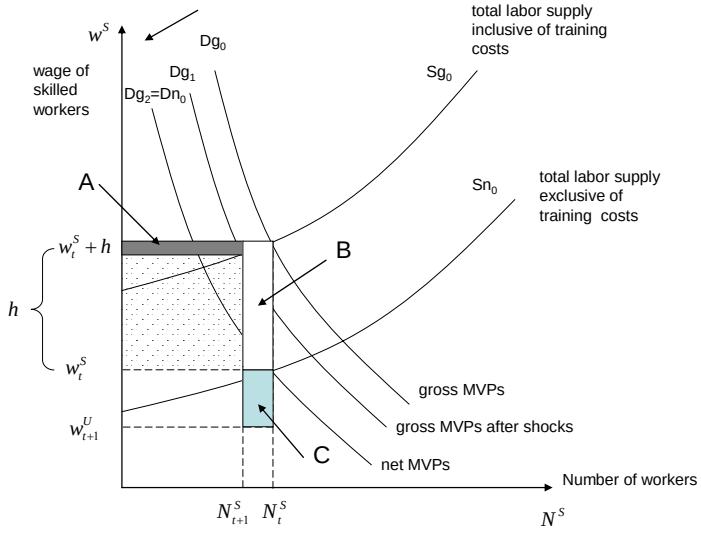
(6) Max $\pi_{t+1} = \mathrm{P}_{t+1}(Q_{t+1}(N^S_{t+1}))Q_{t+1}(N^S_{t+1}) - w^S_{t+1}N^S_{t+1}$
w.r.t. N^S_{t+1}

In this second stage, it is initially assumed that the firm is committed to the wage rate, w^S_t, which was determined in the first stage, while there is a residual return to the initial human capital investment, which is denotated as θ^S_{t+1}, with the gross returns, per unit of retained labor, being $v^S_{t+1} = \theta^S_{t+1}(N^S_{t+1}) + w^S_t$.

As depicted in Figure 3c, to the extent that that retained workers are willing to renegotiate their salaries, a corresponding bargaining solution can be characterized. With such a wage-bargaining outcome, the workers also incur sunk cost losses, represented by the rectangle 4, since the new equilibrium outcome entails a lower wage, specified as $w^{S,b}_{t+1}$, for those workers who maintain their jobs, while others lose their jobs. Displaced workers incur sunk cost losses, represented by the rectangle 6, which can be augmented by as much as the area 7, depending on the opportunity cost of their wages, w^U_{t+1}, as unemployed workers.

Figure 3b

Ex Post Analysis of Labor Market Equilibrium with Firing and Firm-Specific Human Capital



w_t^S : wage rate for skilled workers, when training costs are borne by firms

w_{t+1}^U : compensation for the unemployed in period t+1

$N_t^S(N_{t+1}^S)$: number of skilled workers hired *ex ante* in period t (retained *ex post* in period t+1)

h : costs per worker of training

$MVPs$: marginal value of product of skilled workers

: *ex ante* training costs

: A – sunk costs borne by remaining workers due to lower wages

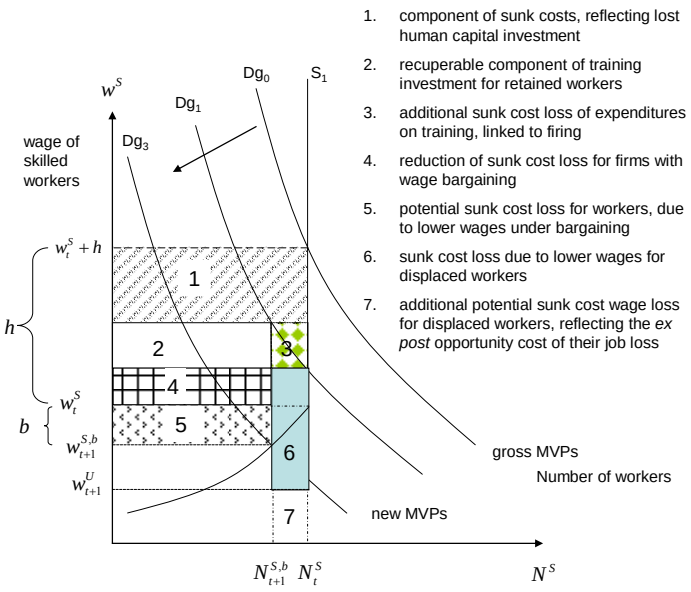
: B – sunk costs for workers losing jobs

: C – sunk cost loss due to lower wages for displaced workers

Figure 3c

Ex Post Analysis of the Distribution of Sunk Costs with Firm Specific Human Capital,

under Alternative Bargaining Solutions



1. component of sunk costs, reflecting lost human capital investment
2. recuperable component of training investment for retained workers
3. additional sunk cost loss of expenditures on training, linked to firing
4. reduction of sunk cost loss for firms with wage bargaining
5. potential sunk cost loss for workers, due to lower wages under bargaining
6. sunk cost loss due to lower wages for displaced workers
7. additional potential sunk cost wage loss for displaced workers, reflecting the *ex post* opportunity cost of their job loss

w_t^S : wage rate for skilled workers, when training costs are borne by firms

$w_{t+1}^{S'}$: wage rate for skilled workers, following a macroeconomic shock in period t+1

$w_{t+1}^{S,b}$: bargaining wage rate for retained skilled workers in period t+1

w_{t+1}^U : compensation for the unemployed in period t+1

N_t^S : number of skilled workers hired *ex ante* in period t

$N_{t+1}^{S,b}$: number of skilled workers kept in period t+1 under bargaining solution

h : costs per worker of training

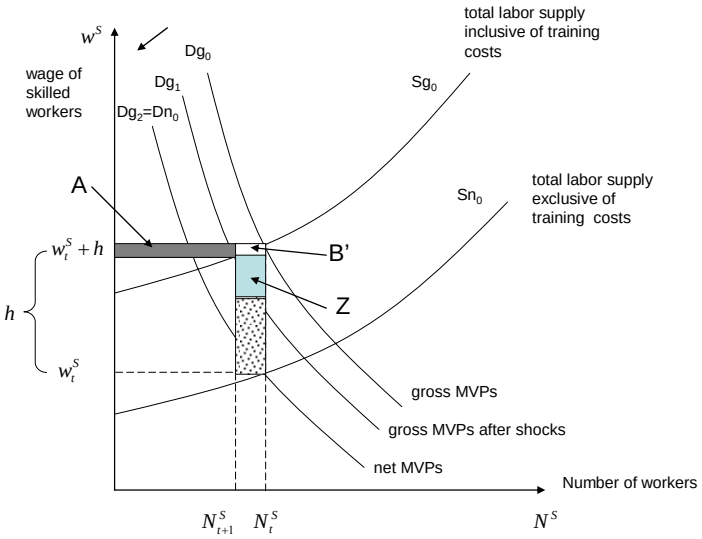
$MVPs$: marginal value of product of skilled workers

As illustrated in Figure 4, the possibility of an outside market for the sales of generic human capital radically changes the distribution of the sunk costs and the wage, employment and unemployment implications of the unanticipated macroeconomic shock. Critical issues for defining the distribution of sunk costs are which agent(s) incurred the initial human capital investment costs, who has the proprietary rights to such generic human capital and its returns, as well as the extent of its substitutability with human capital in other markets. In a scenario where workers, holding such generic human capital, can find alternative employment elsewhere, wages and employment will decline in the initial sector, which is subject to the negative demand shock. If workers initially paid for the investment in generic human capital, the sunk costs resulting from that shock will be distributed across the remaining workers in that sector and the workers who have either lost their jobs or found employment elsewhere, as illustrated by, respectively the rectangles A and B'. However, displaced workers will incur additional sunk costs, represented by the rectangle Z in Figure 4, if there are eventual transactions costs, arising from reallocating their generic human capital to the other labor market.[16]

[16] Of course, if the firm incurred the initial costs associated with the generic human capital investment, it will bear a sunk cost loss corresponding to the full rectangle in Figure 2, while displaced workers may actually gain from selling their services for higher that the initial wage, w_t^S.

Figure 4:

Ex Post Analysis of Labor Market Equilibrium with Firing and Generic Human Capital



w_t^S : wage rate for skilled workers, when training costs are borne by firms

$N_t^S(N_{t+1}^S)$: number of skilled workers hired *ex ante* in period t (retained *ex post* in period t+1)

h : costs per worker of training

$MVPs$: marginal value of product of skilled workers

: *ex ante* training costs

: A – sunk costs borne by remaining workers due to lower wages

: B' – sunk costs for workers losing jobs

: Z – additionnal sunk costs corresponding to reallocative transaction costs for displaced workers

IV . Sunk Costs and "News": A Central Modeling Selection Problem and Redefinition

The analysis of this section highlights further how economic consequences of the irreversibilities embodied in sunk costs can be crucially defined by "news" and the associated strategic interactions between agents. More specifically, the present research initially offers an extension of the analysis proposed in Owen and Ulph (2002), based on a further model simulation and extended interpretation of associated findings. The analysis thereby suggests a need to redefine sunk costs by distinguishing between *ex ante* and *ex post* evaluations of sunk costs, in light of the impact of unforeseen contingencies on irreversible dimensions of investments. As a consequence, there exists a sub-category of sunk costs, which are state and time contingent. The analysis thereby suggests a central identification problem in economic modeling, which results when agents, having internalizing new information, potentially reformulate their optimal decisions in light of strategic interactions with other agents. As a consequence, existing economic models, based on assumptions of known irreversibilities, may not adequately capture subsequent structures arising from unanticipated economic shocks.

The two-country oligopolistic model proposed by Owen and Ulph (2002) offers a framework for considering a nexus of issues concerning the interrelation between market contestability, expectations, strategic interactions between agents and their interrelation to the impact of an unanticipated integration shock. The analysis highlights how different configurations of fixed and sunk costs determine distinctive sets of ex post equilibria, following an unanticipated integration shock, or, alternatively, the revelation of pure news. A crucial distinction is made between fixed costs and sunk costs. While the latter generate exit costs, the former do not. More specifically, fixed costs are understood to involve the creation of an asset that has a proprietary value to an agent within a given time period, but continue to be equally valued by other agents at the end of the period.[17] As such, while fixed costs entail identical repeated flow expenditures in successive time periods, at the end of any given period, the associated assets can be fully liquidated in outside markets without any loss in value relative to the initial investments. In contrast, sunk costs arise when an asset only has value to the agent creating it, so that there is no resale value on outside markets. Hence, unlike sunk costs, fixed costs generate firm specific exit costs, when ceasing operations.

An initial autarkic steady-state equilibrium is defined by the endogenous entry of the oligopolistic firms, producing a single homogeneous good, in each of two countries. These markets are, however, for simplicity, assumed to be identical. Under the initial scenario of infinite trade costs, assuming Cournot-Nash behavior, and under the free-entry condition that the present discounted value of profits is zero, n_0 identical firms set up production in each country's market.[18] The firms make their sunk-cost commitments,

[17] A special case is when the fixed costs disappear at the end of a given period, so that there is no residual asset value for any agents.

[18] This initial number of the entrants depends inversely on the overall *ex ante* levels of fixed and sunk costs that the firms face in acquiring a given technology and obtaining market access.

which are essential for market entry, under the assumption that a state of autarchy will prevail indefinitely.

A second steady-state equilibrium is then examined, following "news" of an unanticipated integration shock between the two economies, in the sense that the variable costs of serving markets fall to zero. Since firms initially assign a zero probability to this event, which is then actually realized, the unanticipated reduction of variable trade costs corresponds, in terms of expectations and the agents' information sets, to a "big bang" event. As such, the integration shock constitutes a form of "pure news".

The analysis then characterizes the firms' entry and exit decisions in the two markets, following the integration shock. It thereby highlights how different endogenous industrial structures emerge, which correspond to three distinct trade regimes. Thus, relative to the initial number of n_0 firms in each country, a critical consideration is how many of these firms, N, will survive in each country, and, of those, how many firms, E, will export. These numbers are shown to depend on the configuration of prevailing sunk and fixed cost. More specifically, it is shown that there is a unique mapping from constellations of fixed and sunk costs to the three different trade regimes. These correspond to traditional trade theory, "new" trade theory, and a distinctive market access regime. The latter set of equilibria had not previously been identified. It is a scenario where the *ex post* evaluation of an specific set of sunk costs – those linked to establishing market access - plays a dominant role, relative to other *ex ante* fixed and sunk cost commitments.[19] In comparison, the "new" trade theory is a regime where fixed costs, again linked to obtaining market access, have a preponderant influence. These fixed costs capture lumpy irreversible expenditures within a given time period, which are internalized in the firms' beginning-of-period decisions. Finally, the equilibria corresponding to traditional theory are those where neither fixed, nor sunk, costs of market access are relatively important, when compared to other *ex ante* cost commitments.

More specifically, the fixed and sunk costs are both broken down into two categories each, relating to technology and market access costs. In the proposed infinite horizon setting the fixed costs are non-compressible costs that are repeated each period that are not agent specific and can be regarded as maintenance costs of remaining in the market. As such they do not entail any residual costs if at a designated future time the agents were to leave the market. In contrast, the sunk costs correspond to irreversible losses of value from to initial investments that are agent specific and are understood to prevail given their understanding of the existing anticipated states of nature. The sunk costs of initially acquiring a technology are denoted by S_T, while F_T represents the fixed technology costs of subsequently using a given technology in each period. Thus, in the proposed model these respective technology costs are essential for initial establishing, and then maintaining a given technological base, corresponding to a fixed marginal cost of production. Analogously, the costs of accessing a new market, are divided into both sunk and fixed cost components, while S_A and F_A constitute, respectively, sunk and fixed

[19] A distinctive feature of our modeling analysis of the economic integration process is that, unlike in the papers by Smith and Venables (1988, 1991) and Venables (1990a,b), we allow for the effects of hysteresis, as captured by the role of sunk costs.

market access costs.[20] These market access costs entail, respectively, the expenses needed to establish market entry and then subsequently service a market(s) during a given period. Although the mechanisms determining such realized sunk costs are not made explicit, a complete set of feasible fixed and sunk cost values are considered.

It is shown that the nature of the post-integration equilibrium, and associated welfare changes, are crucially dependent on the relative significance of market access costs and fixed costs, in relation to the total costs, which are initially incurred by the firms in a state of autarchy. Thus, the following two crucial variables can be used to capture the principal findings of the analysis:

α - the ratio of market access costs (both sunk and fixed) to total fixed and sunk costs;

ϕ - the ratio of fixed costs (both production and market access) to total fixed and sunk costs.

Formally, these are given by:

$$(7)\quad \alpha = \left(S_A + F_A\right)/\left(S_T + F_T + S_A + F_A\right); \quad \phi = \left(F_T + F_A\right)/\left(S_T + F_T + S_A + F_A\right).$$

The following two additional variables turn out to be useful for determining certain properties of the model:

$$(8)\quad \gamma = F_A/\left(S_T + F_T + S_A + F_A\right); \quad \nu = \left[\left(n_0 + 1\right)/\left(2n_0 + 1\right)\right]^2.$$

More specifically, the first of these latter two variables denotes the ratio of fixed market access costs to total costs, while ν is the ratio of operating profits, when there are $2n_0$ firms serving each market, as compared with the firms' operating profits when there are just n_0 firms serving each market. As such the variable ν gives a measure of the maximum increase in competitiveness that can arise post-integration, when all firms survive and serve both markets.

The analysis in Owen and Ulph (2002) shows that there are three distinct trade regimes, labeled as a classical trade paradigm (R1), "new trade" theory (R2) and a market access regime (R3). Each regime is characterized by a set of unique functional forms for its structural equations and the associated, *ex post* welfare changes. It is demonstrated that the emergence of the distinctive set of structural equations characterizing these alternative trade scenarios, depends critically on specific underlying configurations of fixed and sunk costs. Following the unanticipated integration shock, the structure of these costs determine the number of firms initially present in each autarchic country, which will survive and, eventually, serve the other country's market through exports. Each of the three trade regimes is also shown to entail distinctive sets of changes in economic welfare, following the integration shock.[21] These welfare changes, measured

[20] Following a market integration shock, firms, which are incumbents in a given market, have to decide whether or not to incur the market access costs (sunk and fixed) of entering the other country's market.

[21] Alternative formulas, specifying the specific set of structural models for each of the three post-integration regimes, are presented in Owen and Ulph (2002). The initial number of firms in each country, n_0, in the autarchic equilibrium plays a critical role relative in these formulas and the associated welfare calculations.

in terms of consumer and producer surplus, are shown to critically depend in a continuous way on alternative combinations of the fixed costs, which are known *ex* ante and on specific sunk costs – those relating to market access. These can assume different *ex post* values, relative to the total of the fixed and sunk costs, which initially determined market entry under autarchy.

These sets of different equilibria, corresponding to the three distinct trade regimes, are represented in Figures 5a and 5b by contiguous regions, which depend crucially on the two variables, α and ϕ. Figure 5a shows, how the ratio of market access costs to total costs, α, and the ratio of fixed costs to total costs, ϕ, define three distinct sets of equilibria. Figure 5b offers a further simulation, not reported in Owen and Ulph (2002), of the model for specific parameter values. It depicts the associated changes in welfare, defined as the sum of consumer surplus and producer surplus (firms' profits), following the integration shock. The associated structural equations, which specify sufficient conditions for each of the three regimes to arise, along with certain other regime characteristics, are now elaborated below.

Note Figure 4a is to be renumbered to 5a.

Figure 4a

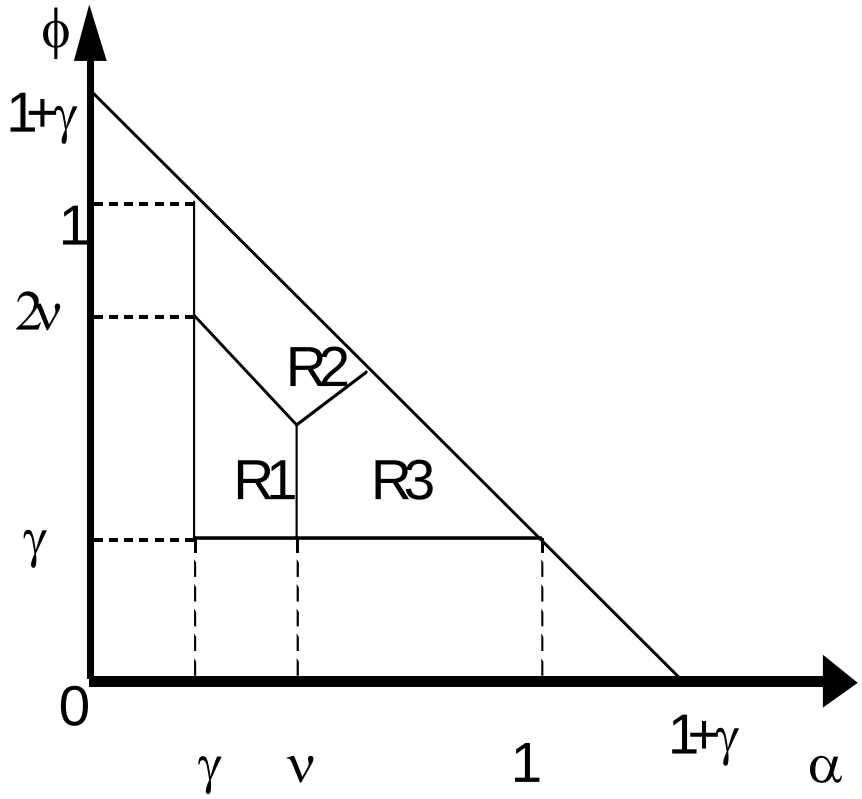


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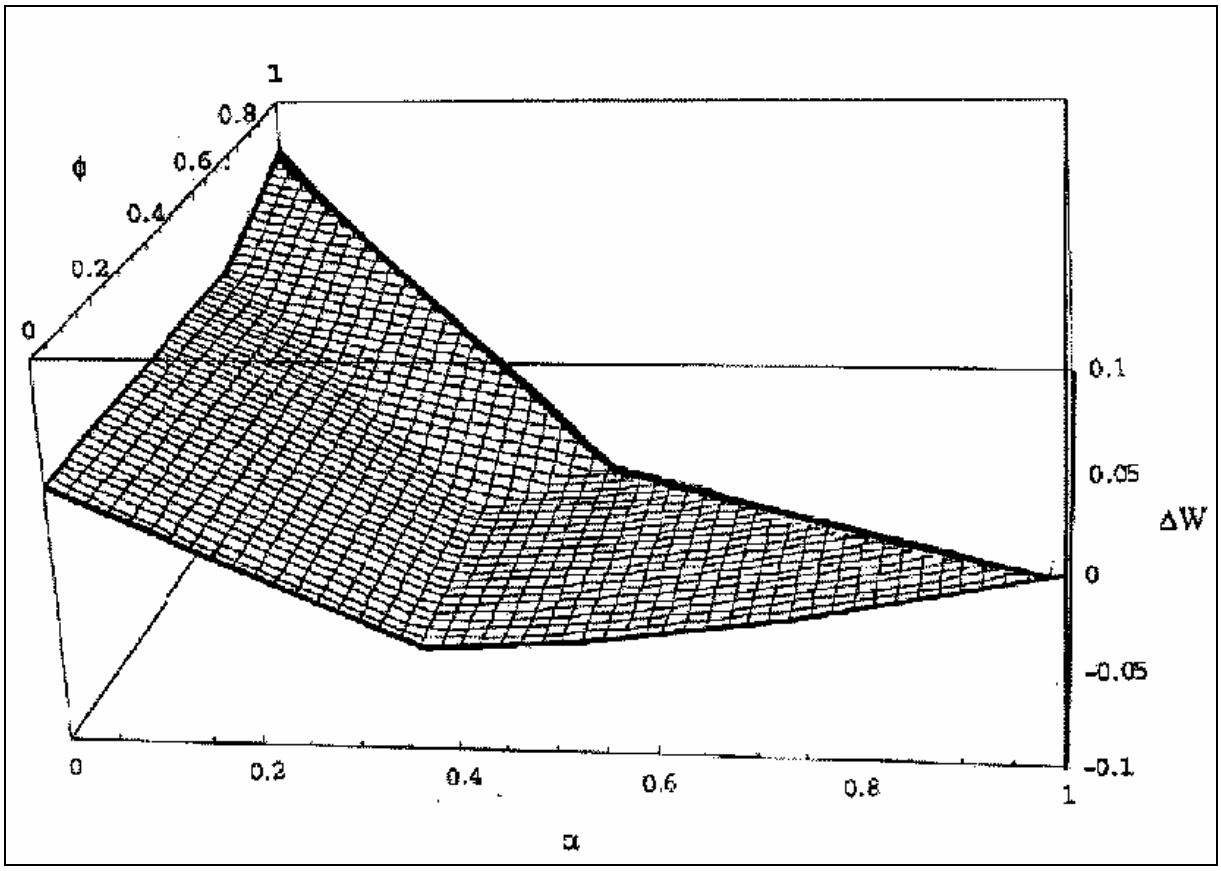
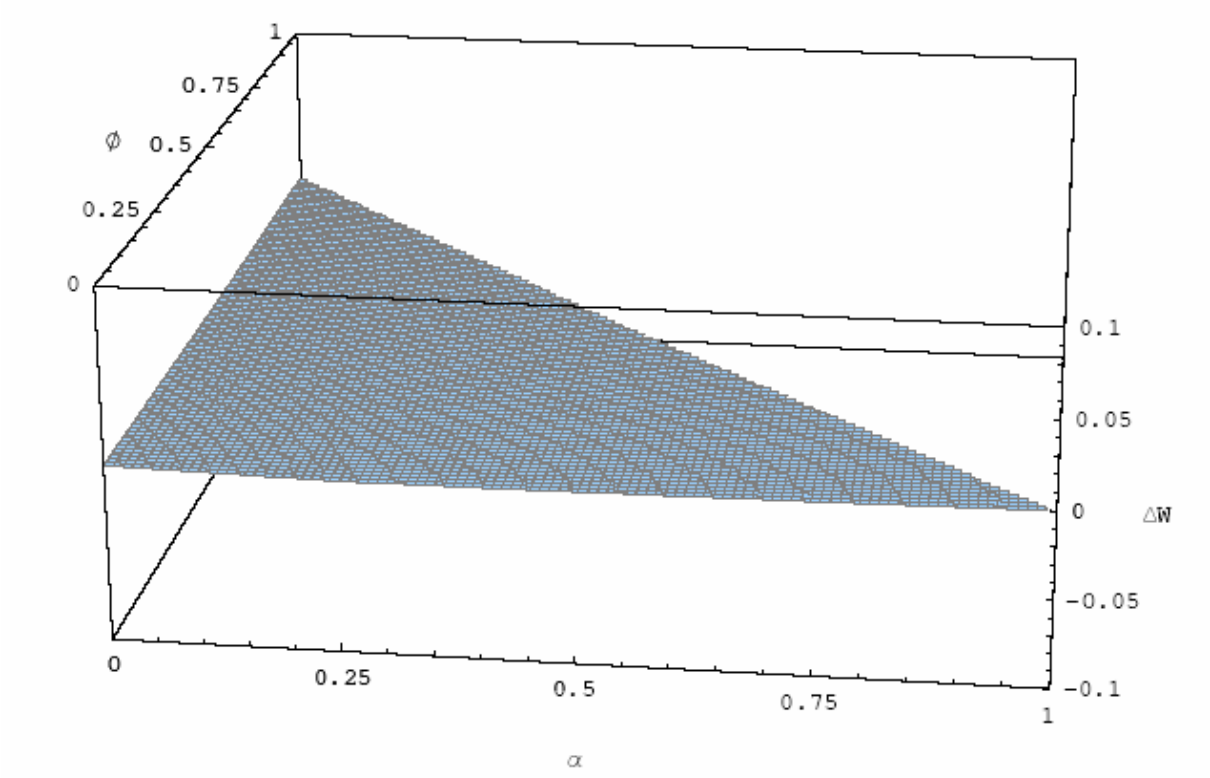
Figure 5b



Technical Note: The parameters used in this simulation are $n_0 = 2$ and gamma = 0.

Figure 5c



Technical Note: The parameters used in this simulation are n_0=100 and gamma = 0.

Regime 1 (R1) The Traditional Trade Theory Regime

(9) $\alpha \le \nu$ and $\alpha + \phi \le 2\nu$.

In this traditional trade theory regime, where all firms survive and all firms export, so that $E = N = n_0$, both fixed costs and market access costs are relatively small.

Regime 2 (R2) The New Trade Theory Regime

(10) $\alpha \le \phi$ and $\alpha + \phi > 2\nu$.

In this new trade theory regime, where economies of scale are paramount, some firms are driven out of the market, but all the surviving firms export, so $n_0 > N = E > 0$. Here

market access costs are relatively small in relation to fixed costs. As in the previous regime, economic integration generates welfare gains when market access costs are sufficiently small, but welfare losses when market access costs are large.

Regime 3 The Market Access Regime

(11) $\alpha > \nu$ and $\alpha \geq \phi$.

In this regime all firms survive, but only some of them export, so $n_0 = N > E > 0$. This is a new scenario where market access costs are the dominant consideration, we refer to it as the market access regime. In this regime, while the net change in welfare is always negative, it is strictly increasing in market access costs, as represented by α.

As shown in Figure 5b, there is a unique mapping relating the welfare changes for each of the foregoing three trade regimes to the configuration of sunk and fixed costs.[22] Accordingly, without knowledge of these underlying costs, each of these regimes can not be identified. Hence, a central finding is that to the extent that sunk costs are ignored in the analysis of economic integration there are associated modeling misspecifications and miscalculations of welfare changes. Furthermore, when there are economic shocks and/or news, sunk costs are the source of distinctive hysteresis effects in economic adjustment processes. However, it should be emphasized that the second-best environment of imperfect competition, in combination with strategic interactions between agents, is crucial for these identification issues to arise. More specifically, as illustrated in Figure 5c, the distinctive welfare effects characterizing each of the regimes tend to disappear as the number of firms approaches a competitive equilibrium.

The critical features of our analysis, which generate the foregoing findings are the highlighting of how fixed and sunk costs account for the initial equilibrium, with strategic interactions between firms, followed by new equilibrium states, which arise because of an unanticipated integration shock. A critical insight is that it is not possible to determine which trade regimes hold, without an understanding of the underlying sunk cost structures. This finding points to a more general central identification problem in economics, which can be stated in the following terms:

Proposition 1: A Central Identification/Selection Problem in Economic Modeling

In the presence of game-theoretic interactions between heterogeneous economic agents and/or at least one market imperfection, a characterization of different categories of sunk costs may be essential for distinguishing between different structural economic relations, when there is "news", reflecting unanticipated economic shocks.

[22] The sunk costs here can be understood to be *ex post* evaluations, following the unanticipated integration shock. The configuration of different structural trade regimes identified in Owen and Ulph (2002) does not depend on whether the *ex post* and *ex ante* are the same.

Thus, unanticipated irreversibilities, corresponding then to *ex post* or *de facto* sunk costs, have the inherent potential of generating distinctive identification/selection problems for structural models of economic systems relative to anticipated irreversibilities, as represented by *ex ante* sunk costs and fixed costs.[23]

The foregoing proposition is based a distinctive formulation of the notion of sunk costs, relative to existing literature. That definition is as follows:

Proposed Definition of Sunk Costs

Irreversibilities associated with investment decisions are at the origin of sunk costs, which are defined here as irrecuperable differences between the initial, historic market value of *ex ante* investment expenditures and the maximum of the subsequent spot evaluations for either their residual market value, or the discounted present value of the returns to that investment, at a particular subsequent period of time. [24]

There are two categories of sunk costs. On the one hand, *ex ante* sunk costs, and, similarly, *ex ante* fixed costs, can be considered (often by way of simplification), as fully anticipated. As such they are already fully internalized in agents' optimal decision-making processes. On the other hand, *ex post* or *de facto* sunk costs are those, which actually arise following a partially, or completely, unforeseen contingency. Accordingly, an economic shock and an associated revelation of "news" can generate a difference between *ex ante* and *ex post* evaluations of sunk costs.

In sum, the appropriate formula for the market evaluation of *endogenous* sunk costs in period t, in light of an investment in an initial period, 0, is:

$$\textbf{(12)} \qquad SC_t = \lambda_t I_0$$

Crucially, whereas the historical decision to commit initially to the purchased of the asset at a value of I_0 is irreversible, the degree of recuperability depends on prevailing market conditions, leading to potential variations over time in the value of λ_t . Furthermore, the existence of transactions costs for selling off the asset drives a wedge between the market evaluation of the sunk cost and the net amount that is ultimately recuperable by the agent in any given period. In addition, the agent needs to compare the present net discounted value (i.e. returns minus maintenance cost) of the returns to holding the asset in relation to its spot liquidation value.

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[23] Such ***ex post* sunk costs** could also be designated as **endogenous sunk costs**. This alternative terminology was suggested to me by François-Charles Wolff.

[24] While a consideration of sunk costs, in the spirit of existing treatments of this subject, might focus on scenarios where there are losses, relative to initial investment expenditures, it should be recognized that changes in the value of investments may be either positive or negative. As emphasized later, it is decisions in time, which are fundamentally irreversible, and not economic values.

In the context of the foregoing central proposition regarding the potential role of *ex post* sunk costs in identifying the structure of economic systems, "news" is understood to constitute new information not in agents' existing information sets. Although this proposition was demonstrated by Owen and Ulph (2002) in a specific economic context for the case of "pure news", it undoubtedly also applies when economic agents partially, but not fully, anticipate future shocks.[25] A key insight is that when economic agents' information sets, regarding future states of nature, are incomplete, *ex ante* and *ex post* decisions can potentially differ, and depend critically on the value of sunk costs, at the specific moment in time when information is revealed. In contrast, to the extent that agents have a full understanding of all future events, they will already have internalized the effects of sunk costs in their decisions. Alternatively, consider an initial steady state for an economy in general equilibrium where all agents have optimized their objective functions. Then, let us envisage an economic shock, which was not anticipated by at least a subset of agents, then those agents will be compelled to reoptimize, and thereby internalize new information in their decisions and strategic interactions in a new general equilibrium outcome. In such a scenario, past commitments, represented by prevailing sunk costs will potentially impact the agents' decisions, but the implicit *ex post* value (or returns) from those sunk cost investments/commitments will be defined **endogenously** by the new general equilibrium steady state. In other words, "news" redefines the value streams associated with past commitments, as a result of revised general equilibrium interactions between agents, who are internalizing such new information in their potentially revised decisions.

The proposed redefinition of sunk costs in *ex ante* and *ex post* terms can beneficially be related to that for fixed costs, which, however, do not entail exit costs. Fixed costs are understood to entail expenditures, over a given period of time and, eventually, the associated creation of an asset, which has a known value on external markets.[26] Hence, the value of a fixed cost incurred by a specific agent is hypothetically the same as that for other agents, in a comparable economic situation, and is constant within a given time framework.[27] Furthermore, it does not give rise to specific opportunity costs for that agent, if the agent were to envisage exiting markets at the end

[25] To the extent that agents can be viewed as assigning *ex ante* probabilities to such partially anticipated shocks, the *ex post* realization of such an event confirms an incompleteness in the agents' *ex ante* information sets concerning the likelihood of its occurrence. Expressed differently, there is an inherent contradiction between *ex ante* expected utility analysis and the *ex post* realization of events. This is reflected in what could be termed "partial news", whereby agents' prior probabilities must be revised once conceivable events, contained in the agents' information sets, actually occur.

[26] Since the value of the fixed cost is known, it is inherently characterized by "lumpiness".

[27] Over different sub-periods of time, there may be known irrecuperable changes in the values of such fixed costs due to market forces, as in the case of a specific rate of capital depreciation, which applies for all agents. Although this constitutes a irreversibility in value over time, critical factors which demarcate sunk from fixed costs are whether there are "exit" costs associated with the initial investment and whether such losses have already been fully internalized in agents' *ex ante* optimization decisions. A further related issue is whether such a change in value constitutes an overall systemic market risk, with uniform effects across agents, or, what is typically a more likely scenario, engenders distributional implications, across different agents, stemming from *ex post* changes in the value of their initial asset commitments. Thus, if an unforeseen event occurs, then what was initially viewed as a fixed cost, may entail a degree of sunkedness *ex post*, and force the agent to leave the market. As pointed out latter, such sunk costs can entail divergences between *ex ante* and *ex post* returns to, and/or the resale value of, the investment or commitment.

of a period of reference. In contrast, as defined here, a sunk cost is characterized as an investment for which there is an irreversibility such that a discrepancy exists between the *ex ante* and *ex post* market evaluation of that asset over a given time horizon, and as such there is an irrecuperable lose of value.[28] Such a form of irreversibility for the value of an asset, which can be either created or purchased, may arise for different reasons. The investment may only have a residual value to the agent itself, which differs from that in outside markets, because of transactions costs associated with, for example, the process of market entry and sales, or asymmetric information between agents.[29] This is illustrated by the example of a recently purchased car, for which there may be an important discrepancy between its sales value, in light of the prevailing market rate for its capital depreciation, and the use value for its owner. Such a discrepancy can determine, then, whether the agent will enter or exit the car market, as well as an evaluation of the associated sunk cost.

The distinction between *ex ante* and *ex post* sunk costs can be represented more formally by considering the evaluation over time of an initial investment by a representative agent. Let I_1^0 denote the initial value of an investment of type 1, at time 0. Then the *ex ante* sunk cost at a future time, *t*, evaluated at the time of that investment, can be expressed in terms of the difference between the expected value of the investment at that time, 0, and its anticipated residual, or scrap, value at that time, *t*,

$$(13)\quad E_0(S_1^{0,t}) = I_1^0 - E_0(I_1^{0,t})$$

Analogously, over time the evaluation of the *ex ante* sunk cost can vary and be expressed, as of a subsequent period *k*, as:

$$(14)\quad E_k(S_1^{k,t}) = I_1^0 - E_k(I_1^{0,t})$$

These expressions can then be compared with an evaluation of the *ex post* sunk cost in periods *k* and *t*, when the sunk cost value is either relevant for evaluating an agent's decisions, or is finally "called", in the sense that the sunk cost is actually realized:

$$(15a)\quad S_1^{k,t} = I_1^0 - I_1^{k,t}$$

$$(15b)\quad S_1^{t,t} = I_1^0 - I_1^{0,t}$$

V. A Revised Formulation and Taxonomy of Sunk Costs in Light of Their Systemic Role

[28] Although the terminology, "sunk costs", implies losses, changes in value, linked to irreversible decisions, can clearly be positive as well. It is decisions in time, rather than values, that are fundamentally irreversible.

[29] It should be stressed that there may be important invisibilities, which hamper the evaluation of such sunk costs at a more systemic level, due to segmented information sets across economic agents.

A. Sunk Costs and Uncertainty

Existing economic research appears to have obfuscated this critical distinction between ***ex ante* and *ex post* sunk costs,** which is essential for understanding a wide range of economic phenomena. Moreover, the potentially critical role of ***ex post* sunk costs** in defining structural economic models has not been recognized. A key insight is that "news" which means that previously optimal ex ante decisions may generate economic scenarios where ex post sunk costs "bite" in the sense that they impact the revised decisions of economic agents. In effect, such *de facto* sunk costs introduce an additional constraint, which can redefine agents' optimal choices.

When an agent undertakes an initial investment in a tangible or intangible asset at period t_0, it must be the case that the present discounted value of the return from that investment is at least as great as the costs being incurred, so that:

$$(16)\quad PDV_0 \geq c_0$$

Alternatively, if V_t and r_t represent, respectively, the value of the return from an investment and the interest rate at time t, the foregoing relation can be expressed more explicitly, over a time horizon of n period, as:

$$(17)\quad V_0 + V_1 / (1 + r_0) \ldots + V_k / (1 + r_0)^k \ldots + V_n / (1 + r_0)^n \geq c_0$$

Now, let us consider certain implications of an economic shock at a subsequent period designated as *k*. At the moment of such a shock there are two facets to the *ex post* evaluation of the residual value of the initial investment/commitment. First, to the extent that the initial asset continues to yield returns, over an ongoing time horizon, to the economic agent, who currently owns the property rights for that asset, those can be expressed as a residual present discounted valued:

$$(18)\quad PDV_k^* = V_k^* / (1 + r_k)^k \ldots + V_N^* / (1 + r_k)^N$$

Note that the economic shock, or alternatively "news", can potentially impact the agent's evaluation of the return, V_k^* in period *k*, as well as in the subsequent periods over the remaining timing horizon until period N.[30] Furthermore, both the interest rate, r_k, and relevant time horizon may be modified by the news. These potentially modified values will be determined as a result of a general equilbrium process in which agents will be strategically internalizing the implications, if any, of the economic shock for their optimal decisions.

Similarly, the economic shock will "call" the residual market value of the asset at the time *k*, which can be designated as c_k^*. Consequently, as a result of changed economic environment, the economic agent then faces a choice of whether to keep the asset or sell it, depending, respectively, on whether:

[30] An asterisk has been used to distinguish these flow values of returns to the asset, since they may differ from the initial *ex ante* values.

(19a) $PDV_k^* \geq c_k^*$

or

(19b) $PDV_k^* < c_k^*$

B. Towards a Reformulation of Sunk Costs

Let I_0 be the value of an investment at an initial period of time, designated as t_0. Then, the associated benefits, $E_0(B_0)$, to such an investment, as of this initial point in time the expected present discounted value of the returns, which equals $\sum B_t./(1 + \delta_t)$, where δ_t represents the applicable interest rate for the successive periods. For a rational agent to undertake such an investment, it must be the case that

(20) $E_0(B_0) \geq I_0 + Z_0 + E_0(M_0) - E_0(V_t) + E_0(Z_t)$

Here, Z_0 represents the non-recuperable, and hence sunk, transaction costs of entering the market in order to realize that investment, while $E_0(M_0)$ is the discounted present value of the maintenance costs, as of t_0 , over the relevant time horizon until the asset would be liquidated, at period t_n . Note that this transaction cost variable Z_0 reflects the efficiency, or alternatively, the liquidity of the market for that investment in the initial period. $E_0(V_t)$ represents the anticipated scrap value of that asset at a future time t, as perceived at time 0. This does not include the state dependent value of the transactions costs, Z_t of a future market reentry the market to sell off that asset.

Let us also again define a parameter $\lambda_{0, m}$, such that $\lambda_{0, m} \in [0, 1]$. This parameter captures the share of the initial value of the investment, I_0 , which is considered to be non-recuperable at t_0, with an anticipated liquidation of the asset by period m. Hence, the *ex ante* value of this anticipated sunk cost is defined by:

(21) $SC_{0, m} = \lambda_{0, m} I_0$

Hence, the evaluation of the extent of *ex ante* irreversibility can be expressed as:

(22) $SC_{0, m} = \lambda_{0, m} I_0 = [I_0 + Z_0 + E_{0, m}(M_t) + E_0(Z_m) - E_0(V_m)]$

Key features of the foregoing expression is that extent of sunkedness of the initial investment potentially comprises both a component, which is determined when an asset is initially acquired, and evaluations which are contingent on future states of nature, when an asset is subsequently liquidated. Paralleling this remark, is the observation that whereas the historical value of the investment, I_0 , can be viewed as exogenously given, from a partial equilibrium perspective, at a given moment in time, the extent of irreversibility is potentially endogenous with the evolution of economic systems and associated revaluations of asset values.

Certain critical insights regarding implications of *ex ante* and *ex post* sunk costs for demarcating market and non-market activity, can be obtained by analyzing

implications of "news" for spot evaluations at a future time, t_1. Such news can entail revealed information previously outside either the representative, or other, agents', initial information sets. Such redefined sets can potentially impact the present discounted value of benefits from an investment, and/or the residual spot market value, if any, of that investment, I_1.

More specifically, let us consider three hypothetical cases, reflecting the representative economic agent's initial assessment of the extent of irreversibility at the time of the investment, as reflected by the value of λ_0.

First, let us consider an *ex ante* scenario of full irreversibility, where $\lambda_0 = 1$, so that it is expected that there will be no future residual market value for the initial investment.[31] This scenario can alternatively be interpreted as one of full commitment. This means that an economic agent will hold on to that asset provided the revalued present discounted value of the stream of benefits is greater than the anticipated maintenance costs, minus eventual non-recoverable, spot disposal costs, Z_1, of reentering the market and selling off the asset:

$$(23)\quad E_1(B_1) \geq E_1(M_1) - Z_1$$

It is apparent that the foregoing inequality critically defines the division between non-market and market activities, as well as the extent that history matters, in the sense that an understanding of existing commitments is crucially for defining the subsequent evolution of economic systems. Notably, this distinction can be applied to understanding the borders and interactions between institutions and markets. The former can be though of as imbedding a wide range of sunk costs.

Alternative scenarios for the extent of *ex ante* and *ex post* irreversibilities can be represented by different combinations of values for λ_0 and λ_1. Thus, while initially there may be no anticipated irreversibility, such that $\lambda_0 = 0$, it is quite conceivable that $\lambda_1 > 0$. Such a scenario is illustrated by the discussion in Section II relating to the interrelation between the hold-up problems and lock-in effects. The extent of such *ex post* irreversibilities can critically define not only a given agent's market exit, reentry and performance decisions, but also those of other agents undertaking economic activities, which are interdependent with those of the specified agent. Once heterogeneous agents and initial economic conditions are envisaged for different representative agents, i and j, it is essential to analyze the role of both *ex ante* values of λ_0^i, I_0^i, λ_0^j, and I_0^j and *ex post* values for λ_1^i and λ_1^j. These values define alternative scenarios which capture the extent to which different asymmetries across agents are critical for defining their distinctive reactions to the economic givens of history and the agents reoptimization decisions. Thus, for example, agents with *ex post* sunk costs have reoptimization decisions, which do not incorporate such sunk costs, whereas the optimization for other agents may be critically impacted by their obligation to incur *ex ante* sunk costs. It is precisely this mechanism, which explains the asymmetric positions of incumbent firms and new entrants in the analysis of Owen and Ulph (2002). This in

[31] Nonetheless, it need be recognized that there may, unexpectedly, be a positive *ex post* spot value of the asset, I_1. Such an outcome is implicitly treated in the subsequent discussion of the other cases.

turn generates three distinctive trade regimes and associated identification/model selection problem, as previously discussed.

The forementioned pecuniary externalities arise because of the "big bang" effect of the release of news at a systemic level. More specifically, it is the general equilibrium determination of the interplay between three categories of agents, which characterizes the new equilibrium outcome. With the diffusion of information in an economic system, certain agents will internalize such news and potentially reoptimize their objective functions. In given markets, this process is associated with historical interdependences between new market entrants and existing agents, defined as those with potentially differing degrees of existing market commitments, as reflected by their holdings of assets acquired in the past. A key insight is that the subsequent new general equilibrium outcome results from the interrelation between prevailing configurations of potentially asymmetric optimization problems. In this process certain agents may find that part of the original value of their existing commitments is non-recoverable, and, as such, is a "bygone", while other agents may be undertaking investments without such "historical baggage". Critically, it is the simultaneous interplay between the optimization decisions, impacting that market, which define market entry, exit and related performance. This is a generic issue characterizing not only the impact of new information on the performance of agents and markets, but also, more generally, the processes determining the evolution of economic systems, including the ways and extent to which information itself disseminates over time.[32] The foregoing arguments can be synthesized in the following terms:

Proposition 2: Pecunary Historical Externalities, Sunk Costs and the Identification of Structural Models

In the presence of one, or more, market imperfections, the investment irreversibilities, at the origin of *ex post* or *de facto* sunk costs, can be associated with historical pecuniary externalities, when "news" causes economic agents to reoptimize their decisions. The extent to which the internalization of unforeseen contingencies will cause economic agents to revise economic decisions can depend on the historical time profile and values of their *ex ante* investment decisions, relative to those of other agents, as well as the magnitude of informational and other economic shocks. The pecuniary externalities can arise because of general equilibrium effects on the returns to initial investments and/or due to changes in the residual or scrap value of those investments. These then can generate distinct structural models, depending on the extent of both past and future economic irreversibilities

Let us designate as agents α the **endogenously determined** number of agents that are distinguished by certain irreversibilities and manage to survive in a market, following information revelation in a period t. Then, as previously noted, their optimization

[32] In light of the finiteness of agent's time endowments, the use of time and associated returns to such investment is subject to the same generic issues regarding sunk costs and associated interaction effects, which have been identified here. Notably, this observation is related to understanding the role of learning processes in influencing the endogeneity of preferences over time, along with the economics of reputation.

decision is characterized by a modified and reactualized version of equation 13, but which critically does not include the initial investment and sunk costs of market entry, $I_0 + Z_0$, so that:

$$(24)\quad E(B^{\alpha}_{t}) \geq E(M^{\alpha}_{t}) + E(V^{\alpha}_{t,\,t+k}) - E(Z^{\alpha}_{t,\,t+k})$$

Analogously, $E(B^{\alpha}_{t})$ designates the expected present discounted value of the returns, or alternatively, associated benefits, to an existing investment, as of this period t. $E(M^{\alpha}_{t})$ is the discounted present value of the maintenance costs at that same moment of time. $E(V^{\alpha}_{t,\,t+k})$ represents the scrap value at time t if there is a resale at an anticipated future period t + k, while $E(Z^{\alpha}_{t,\,t+k})$ then indicates the associated costs of market reentry in order to realize that scrap value sale.

A second category of agents β designates those that are entering the market for the first time. In light of the foregoing discussion their optimization decision is given by:

$$(25)\quad E(B^{\beta}_{t}) \geq I^{\beta}_{t} + Z^{\beta}_{t} + E(M^{\beta}_{t}) - E(V^{\beta}_{t,\,t+k}) + E(Z^{\beta}_{t,\,t+k})$$

Finally, a third category of agents, γ, are those that are forced to leave the market in light of the strategic competition with the surviving agents α and new entrants β. Although the number of these agents is not immediately observable from market transactions, their, again, endogenously determined number can define the nature of competition and/or transactions, as well as the terms of those interactions between the α and β agents. Their exit condition is specified by:

$$(26)\quad E(B^{\gamma}_{t}) < E(V^{\gamma}_{t,\,t+k}) - E(Z^{\gamma}_{t,\,t+k})$$

The subsequent new steady-state equilibrium is defined by the simultaneous interplay between the α, β and γ agents.

C. Sunk Versus Fixed Costs and New Decision Branches

The foregoing analysis has pointed to crucial differences in the specifications for sunk and fixed costs, as well as their implications for economic modeling following the revelation of news.

Crucially, endogenous sunk costs entail *ex post* liabilities and potential discrepancies between *ex ante* and *ex post* returns to assets. Consequently, exiting an activity is not frictionless, and there is a critical decision of whether to sell off, or retain the asset, as well as other related investment and/or other reoptimization decisions. Hence, spot market evaluations of the degree of recuperability of the asset, transactions costs for liguidating it, and the returns to the asset are all essential considerations, which define a new decision tree.

More specifically, following the revelation of an unforeseen contingency in period k, the nature of the *ex post* reoptimization branches in a representative agent's decision tree can be defined by a set of inequality conditions. The first of these stipulates when the agent so keep the asset and stay in the market:

(27) If $B_k > M_k$, then retain the asset

Once again, B_k and M_k are, respectively the returns to hold a specific asset and the associated maintenance (or variable) costs. However, the agent should sell off its asset holding if, over the relevant time horizon:

(28a) $V_k - Z_k > B_k$, then sell off the asset

(28b) $B_k < 0 < M_k$ then sell of the asset

Here, V_k and Z_k represent the market value of the asset in period k and the associated, potentially agent specific, transactions costs of reentering the market to sell off the asset. Alternatively, $V_k - Z_k$ can be thought off of the net liquidation value of the asset in the kth period.

In contrast, the *ex post* reoptimization, involving fixed costs, is frictionless, does not entail any market reentry issues, and only relates to flow measures. It can be characterized by the following inequalities:

(29a) If $B_k > F_k$, then stay in the market and continue to incur the fixed cost expenditures.

(29b) If $B_k < F_k$, then exit the market.

Of course, given a specific time framework, the conditions for staying in the market are analogous for fixed and sunk costs, as reflected by the inequalities (23) and (25a). A crucial difference applies for the exiting decisions in the two instances. For fixed costs, exiting is essentially frictionless, while the relevant return is that obtained by the agent. In contrast, in the case of sunk costs, market evaluations serve as a critical point of reference, while there is a stock evaluation questions relating to the value of the asset. In particular, the potential transactions costs of market reentry, in order to sell off an asset, potentially drive a wedge between market and private returns to the asset holding. It should be stressed, nonetheless, that the foregoing discussion of the new decision branches for the agent have not considered the possibility of additional investments, which could be either complementary, or substitutes, in relation to the existing asset holding.

D. Sunk Costs Matter

The foregoing analysis suggests what might be called the "sunk cost trilogy". More specifically, the state contingent irreversibilities, embodied in sunk costs, can matter for market entry, market performance and market exit decisions. While it is well recognized in the industrial organization literature that *ex ante* sunk costs can determine market contestability. For an individual agent, market entry occurs when anticipated

returns are greater than anticipated sunk costs. What is perhaps less appreciated is that there is a potential discrepancy between the partial equilibrium calculations of individual firms, for example, and the associated general equilibrium outcomes. More specifically, sunk costs can be associated with both costs which are not fully determined at the time of an initial investment and streams of returns to investment over time. These can have quite different *ex post* evaluations, relative to an individual agent's *ex ante* assessment of their future value, once a general equilibrium outcome is determined. Clearly, with more heterogeneous agents, more incomplete information spaces, and higher degrees of uncertainty, the greater are the potential discrepancies between exogenous specifications for the partial equilibrium evaluations of individual agents, and the endogenous evaluations in general equilibrium evaluations. Thus, there is an inherent contradiction in specifications of the role of sunk costs in partial and general equilibrium.

A second part of the "trilogy" is that endogenous sunk cost evaluations can very much matter for an agent's decisions even if these are not related to entry and exit decisions in the specific market where those sunk costs arose. An issue here is that there can be varying degrees of complementarity and substitutability between sunk costs in different markets. This is illustrated by the complementarity that arises between the training of workers in the use of information technologies and investments in computer hardware. A firm, for example, that faces high labor turnover might not be willing to invest in computers with new technological capabilities if it anticipated high additional irreversible losses from the retraining of its existing stock of workers.

A third critical way in which sunk costs can matter is with regard to agent's exit decisions from markets. At a given point in time, an irreversible loss of value in an initial investment implies a spot cost commitment, which is effectively a "bygone" in terms of the agent's decision to exit the market if it does so because the perceived present discounted value of the returns to that investment are less than the residual value of the asset. It can be noted that this evaluation may be contingent on changes in other markets, as arises when goods with superior characteristics become available at affordable prices. Yet, when the agent decides not to liquidate the asset and thereby stays in the given market, the irreversibility remains as a potential state contingent put option. In this sense, the sunk cost continues to matter. Again, the interrelation between the partial and general equilibrium analysis is crucial for understanding the idea that the *ex post* evaluation of sunk costs may, or may not, matter depending on state contingent outcomes, which depend on the distribution and evolution of information over time.

There are apparent implications of the foregoing analysis for the specification of the conventional utility and profit optimization behavior of consumers and firms. Indeed, much of standard economic analysis is profoundly ahistorical. For example, the standard representative consumer problem,

$$(30)\quad \text{Max } U(X_1, X_2, \ldots X_n) \quad \text{subject to } \sum_{i=1}^{n} P_i X_i = Y$$

essentially freezes the stream of history, since it ignores the determinants of market entry and exit in general equilibrium. These can critically depend on the evaluations of existing stock holdings of goods which are related as substitutes or complements with the set of goods, $X_1, X_2, \ldots X_n$, which are being considered for purchase. If a hypothetical set of such stocks are represented by, $Z_1, Z_2 \ldots Z_n$, then a "history augmented" utility

function could be conceived as being represented by $U(X_1, X_2, \ldots X_n; Z_1, Z_2, \ldots Z_n)$. The critical insight here is that consumers calculation of marginal utilities with prices depends on such stocks, which imbed endogenous sunk cost evaluations, as reflected, for example, by a vector of quality variables $q_1, q_2 \ldots q_n$, which capture the evolution of the goods characteristics over time. Thus, a historical augmented utility function could be represented in the standard Cobb-Douglas case by:

$$(31)\quad U(X_1, X_2) = (X_1 + [Z_1 / q_1])^{\alpha} (X_2 + [Z_2 / q_2])^{\beta}$$

It is a trivial exercise to show that the historical values of such stocks and quality indices impact the agents purchases of X_1 and X_2. Alternatively, these historical stock values could be specified in terms of a series of potential inequality conditions, which need to be verified to ascertain whether the agent will enter or exit the market. Critically, these stock and quality index values embed irreversibilities, which can change endogenously over time as a result of market entry and exit decisions, as in the example, of goods with certain technological characteristics. Furthermore, an agent's preferences, as represented by the coefficients α and β in the Cobb-Douglas, can be understood to evolve over time, as a function of sunk learning costs. Analogous reasoning could be applied to a reformulation of the standard theory of the firm, wherein there are historical values of labor and capital stocks, which have endogenous evaluations in general equilibrium.

Thus a frontier for ongoing research in a wide range of areas in economics entails seeking to identify *ex post* sunk costs and understand their potential implications for existing structural models of economic phenomena, as well as econometric estimations aimed at identifying associated structural changes.[33]

The analysis of ex ante, and ex post, sunk costs is closely interrelated with the analysis of commitment in economics. Indeed, irreversible investment decisions constitute just one form of commitment. The notion of commitment applies to a wide range of other economic phenomena, including notably different contractual relations, such as labor contracts and those imbedded in the internal functioning of institutions, as well as their external relations. Existing commitments can give rise to **ex post, sunk opportunity costs.** These result from at least temporary restrictions on agents' optimal decision spaces and the attainment of higher welfare states. As in the case of ex post sunk costs, the evaluation of sunk opportunity costs is critically defined by different forms of "news", which are *ex post* to the commitment. When an economic agent maintains its commitment, even though there are potentially preferable outcomes, at least in the short run, to decommitting, the agent experiences such *ex post*, sunk opportunity costs. However, at the moment the agent abandons such a commitment, it will be subject to incurring associated sunk costs. This point is illustrated by the case of a central bank, which is seeking to defend the value of its exchange rate during a financial crisis. There can be an opportunity cost to the central bank's using its reserves to defend its currency,

[33] A recent paper by Mailath, Postlewaite and Samuelson (2004) proposes a model of investments in housing with sunk costs and uncertainty. In particular, they consider the interrelation between the agents' investments and optimal savings to demonstrate that, even in competitive markets, unpredictable future housing markets prices can generate inefficient investment and trade. Viewed at a more general level, their findings are consistent with the international trade findings in Owen and Ulph (2002) that when sunk costs are dominant, unanticipated shocks can lead to welfare losses with trade.

but were its intervention to be swamped by speculative forces, it will suffer a sunk cost from the loss of its commitment. That sunk cost will correspond to the value of reserve losses, evaluated at the new ex post, devalued exchange rate.

An unanticipated economic shock can generate an irrecuperable change in value because of *ex* post irreversibilities in decisions, relating to *ex ante* investments or commitments. Such irreversibilities may arise on the expenditure/cost side, or because of either the reevaluation of an asset value or change in the opportunity cost associated with a decision. A essential insight is that sunk costs often arise, *ex post*, because following an unanticipated shock, *ex ante* decisions are not longer optimal and there is an associated opportunity cost to those previous decisions. Thus, sunk costs can, alternatively, be conceived of in terms of either the actually realized changes in values, or in terms of restrictions in sets of previously attainable economic spaces/outcomes. In the latter sense, certain sunk costs can also be viewed as a missed opportunity, and, hence, the opportunity cost of a prior irreversible decision.

A form of duality in economics which may not have been adequately recognized is that whenever there is a commitment there can be associated sunk costs and/or sunk opportunity costs which depend on prevailing states of nature. These can trigger, alternatively, the "calling" of sunk cost values or the unraveling of existing commitments. In order to fully understand such processes it is essential to evaluate both the sunk costs and sunk opportunity costs associated with not only the commitment, but also the conclusion of that commitment. For example, a theory of marriage is incomplete without also a theory of divorce. Analogously, examining the credibility of a central bank's announced commitment to defending a given fixed exchange rate, necessitates an appraisal of the sunk opportunity costs of maintaining or abandoning such a commitment in different states of nature. Similarly the analysis of investment precommitments, reflecting in the well-known "hold-up problem", has a dual in the form of the "lock-in effect", which are both critically related to sunk costs and sunk opportunity costs.[34]

It should be further noted that the very process of decision making, and expectations formation, inherently entails sunk costs, since economic agents invest time and resources to gather information and formulate their decisions. Put differently, sunk costs are an intrinsic feature of economic systems and adjustment processes.

E. Sources of Sunk Costs

Although the role of sunk costs in investment and finance decisions is now well recognized, as investigated by, notably, Dixit and Pindyck (1994), the foregoing definition suggests a much wider array of optimization decisions that can arise beyond those of holding assets or physical and technological investments. Such an expanded array of intertemporal commitments include explicit and implicit contracts, the structures and internal functioning of firms and institutions, and, indeed, many aspects of human behavior, including, notably, learn processes.

Viewed in such a larger context, it is readily apparent that a vaste research agenda lies ahead. Indeed, the role of sunk costs, in impacting economic performance and welfare, in labor economics, international economics, the economics of transition,

[34] Fukuda and Owen (2003) offer an analysis, which illustrates the role of hold-up and lock-in effects in the case of a macroeconomic slowdown and long-term labor market contracts in Japan.

technological competition, behavioral and experimental economics, is but the "tip of the iceberg".

F. On the Measurement of Sunk Costs

A crucial insight is that sunk costs are a form of market failure. Indeed, they are doubly so. First, there is the most obvious loss of value, which a sunk cost can entail. This is apparent in the case of bankruptcy where, for example, there is a likely loss of intangible assets, such as those linked to unfinished technology projects. Such technological investment may have little, or no, residual market value outside a specific firm that initiated those R&D activities. But, there is also a second form of market failure in terms of a potential informational loss, hence a failure, for the efficiency of economic systems as a whole. From the standpoint of the overall economic system, this is a form of incompleteness and defines bounds to the "rationality" of economic agents participating in that system, in the sense that their decisions will not incorporate all potential information. A essential point to stress here is that the informational sets that agents may have regarding a specific sunk cost, may be quite disjoint. *A priori*, the information sets will be most complete for those economic agents, which are closely associated with the intertemporal commitments linked to a given sunk cost.

In many respects, the informational content of sunk costs can be viewed as a private good, which is only partially observable by outside agents. Consequently, those external agents may make decisions, having formulated conjectures regarding their own evaluation of sunk costs, which can entail varying degrees of misperceptions. Thus, a key issue here is that the information sets of agents can vary substantially across an economic population. In order to understand the impact of an economic system engendered by the constraints and other consequences of a specific sunk cost, it is essential to consider the distribution across agents of shares of a hypothetical information set, which would contain all of the hypothetically relevant information relating to the sunk cost. In this respect, it should be noted that the information sets of agents most closely concerned with a given sunk cost may themselves be incomplete, to the extent that they lack information regarding the true opportunity cost of an economic shock. This leads to an inherent identification problem in economics, since it is inherently complex interactions between agents, based on often unobservable factors, which will define structural models. Such an identification problem is further complicated by the possibility of successive unanticipated shocks, which will greatly complicate characterizations of the interfaces between different agents' information sets. From an econometric viewpoint, there is an apparent methodological limitation to forecasting the consequences of given unanticipated external shocks.

Certain of the arguments presented here are in a number of respects analogous to those of the Lucas critique. Yet, there is the further insight that an understanding of whether processes of forming expectations are more akin with that of a frictionless world, or one in which adaptive specifications based on existing equilibria, may be critically explained by the interrelation between expectations formations at the micro level of individual agents' information sets and opportunity costs of processing information, which entail sunk cost issues. Yet again, unanticipated sunk costs can entail an inherent

source of information loss in economic systems, which are essential for understanding the strategic interactions between agents and economic adjustment processes.

G. Effects of Sunk Costs and Related Conceptual Issues

Viewed at a somewhat abstract level, the class of problems identified in this research can be viewed as related to issues in mathematics relating to the analysis of limits and discontinuities. More specifically, the basic expectational framework is one where the initial probability assigned to an event (in this instance the integration shock,) is zero ($p = 0$), whereas the realization of this unanticipated event with certainty, leads to an *ex post* probability of one ($p=1$).

At the time of a "big bang" associated with an unanticipated shock, there is a critical question of how much existing economic structures and relations matter.

Crucial differences exist in the relation between sunk costs and aggregate market performance, on the one hand, and between sunk costs and individual institutions, firms and individuals, on the other hand. By endogenizing exogenous shocks market forces may produce price and quantity changes, which generate sunk costs. As previously noted, this can constitute a form of market failure. Indeed, price, and other, market changes may also be the source of "news", which can, by themselves, be a form of exogenous shock. This idea is illustrated by the effect that stock market movements may have on agents' expectations formations. In contrast, institutions, firms and individuals can often be viewed as imbedding sunk costs that are either generate by market forces, or by their own strategic decisions, or those of others. One mechanism by which such sunk costs arise is through either explicit or implicit contractual relations. Nonetheless, the foregoing distinction may not always be so clear-cut, since explicit and implicit contractual relations between economic agents constitute different facets of market mechanisms.

Note, furthermore, that sunk costs could in certain instances change the preferences of agents. One can imagine, for example, that investors in the stock market might be more risk averse once they experience a loss due to a forced sell off during an economic downturn. For example, less liquid investors could become more risk averse, as a result of an irrecuperable loss of value associated with their having to sell off their holdings during a macroeconomic slowdown. This, in turn, could lead to a dampening of their willingness to reenter the market, thereby accounting for more protracted periods of recession. The very fact that such investors would be leaving markets, would, in turn, lead to the previously discussed identification problem. Thus, for relatively liguidity-constrained investors, knowledge of the timing and prices associated with their initial stock market purchases (market entry) and subsequent sales (market exit) decisions would be, for the most part, private information. Of course, more liquid and diversified investors, which are typically larger ones, would not be as likely to experience such sunk cost losses and would consequently be able to "ride out the storm". A clear implication of the foregoing remark is that modeling efforts to try and capture swings in the shock

market should try to obtain proxies for the number of small, relative to large, investors, as well as associated measures of their degree of liguidity.

History Matters

Hysteresis effects arise when there is a path dependency of equilibria, such that past equilibria impact the trajectory of future equilibria.[35] There are two senses in which the hysteresis effects, arising from sunk costs, could be thought of as impacting the historical evolution of an economy's performance. The first of these relates to the speed of convergence from an initial equilibrium to the final one that would prevail in a frictionless scenario.[36] The second results from a path dependency, which depends on the configuration and levels of sunk costs, such that a frictionless equilibrium is never attained. The latter scenario would arise if there are persistent sunk cost effects which never dissipate. One reason for such sustained hysteresis effects is the informational loss, associated with the market failure nature of sunk costs, is distributed asymmetrically across agents. Furthermore, to the extent that there are divergent information sets across agents, there is the potential for associated changes in agents' strategic decisions, which may be the source of complex interactions. A crucial insight to emerge from the analysis of this paper is that economic irreversibilities influence history not only when they are fully surmised by economic agents, but also when there full implications are not initially understood, because of unforeseen contingencies.

VI. Applications to Different Fields of Economics

These include the realization that:

1. that the economics of institutions, pioneered notably by Williamson (1986, 1990, 1996), involves governance structures and contracts which imbed fixed and sunk costs explaining institutional hysteresis. Indeed, by definition the contractual and non-market exchanges which such institutions engender entail intertemporal commitments, which are regularly subject to external macroeconomic, technology and other shocks from the external market environment. The flexibility of internal management responses to such shocks, in turn, can defined endogenously the extent of *ex post* sunk costs borne by the firm.

2. individual behavior and preferences can both be characterized as being contingent on sunk informational costs, associated with the acquisition of information linked to "learning" and the formation of expectations. Furthermore, strategic, and other, decisions can be viewed as both contingent *ex* ante on such sunk costs, as well as entailing *ex* post sunk costs, which impact on agents' subsequent decisions, strategic interactions and welfare. Indeed, past informational

[35] See, for example, the related discussion by Arrow (2004), which he formulates in a competitive paradigm.

[36] Of course, an additional shock during such an adjustment period would likely mean that such a final frictionless equilibrium would not be reached.

investments may impact agents' future decisions by influencing their willingness to acquire new information.[37] Furthermore, an appropriate way to consider "trees" of intertemporal gaming behavior is to envisage sunk costs as impacting the evaluation of nodes of such "trees". They, thereby, can account for new branches in such decision trees.

A clear implication of our analysis is that the extent to which expectations formation can be viewed as "adaptive", rather than "rational", could critically dependent on whether there are significant sunk costs in economic adjustment processes. In a frictionless world, adjustment is instantaneous and conventional comparative static analysis may be appropriate, without significant concern for alternative dynamic adjustment paths. In contrast, in a world characterized by important sunk costs, hysteresis effects dominate such that past equilibria may play a particularly important role in accounting for new equilibria states. Hence, there are apparent issues relating to the microeconomic foundations of the "Lucas critique", which are imbedded in questions relating to the specification of sunk costs, as state variables that determine unique path-dependent adjustment processes. A critical insight is that, even if the *ex post*, economic influence of sunk costs diminishes (depreciates) the final steady-state equilibrium will be uniquely interrelated to the specific time-profile of their values.

Clearly, to the extent that experimental economic approaches do not explicitly take into consideration such sunk costs of individual decision-making they can entail critical misspecifications. Another issue, which can arise in the case of individual behavior involving strategic interactions between agents, is the idea of reputational hysteresis, which offers additional insights concerning the well-known "lemons" problem set forth by Akerlof (1970).

VII. Conclusion

A central tennet of the foregoing analysis is that sunk costs appear to be one of the most neglected and poorly understood topics in economics. Indeed, the current treatment of sunk costs entails a fundamental analytical flaw, since the postulated past and future roles of sunk costs are characterized in an essentially atemporal fashion, based on an artificial partition of the past and future at a hypothetical moment in time. Such an approach obfuscates the role of sunk costs as state variables, which fundamentally impact agents' choice sets through wealth effects and restrictions on agents' choice sets.

The analysis presented here rests on a central theorem established in the paper by Owen and Ulph (2002). More specifically, it is demonstrated in the context of a two-country model of oligopolistic behavior, that the final equilibria states and associated welfare changes resulting from an unanticipated integration shock depend critically on the combined role of fixed and sunk costs. It is apparent that the modeled market

[37] For example, in the case of reputational hysteresis, agents' judgments of other agents' characteristics may be largely based on the past acquisition of information, which can be perceived as having a residual value.

imperfections and strategic interactions between agents play a critical role in accounting for these findings. In a frictionless world, without any historical "memory" a competitive equilibrium would prevail instantaneously, leading to a different final outcome from the equilibrium from those which are identified in our paper, and shown to be uniquely dependent on underlying cost structures and market imperfections. A clear corollary of the foregoing results is that many existing international trade paradigms have inherent weaknesses, to the extent that they view the world as a frictionless one, in which new trade equilibria are either explicitly or implicitly understood to arise from exogenous shocks. It is clearly essential to model the diffusion mechanisms by which such shocks filter through the economy. In particular, such *tatonnement,* or other adjustment processes, need to consider the effects that sunk costs have as state variables defining the trajectory of equilibria. They can reflect, for example, liquidity and other constraints, as well as wealth effects.

Expressed in other terms, a key contention of this paper is that at the time of a "big bang", associated with an unanticipated economic shock, economic agents' existing commitments play a critical role in defining subsequent economic equilibria and welfare. These *ex ante* commitments correspond, in a very real sense, to the weight of history in influencing economic outcomes. In a frictionless world, with complete markets, history does not matter. However, "for better or for worse, until death does us part", most, if not all of the world in which we live in is characterized, in my view, by the impact of varying degrees of pre-commitments and market imperfections, along with associated hysteresis effects. In this "real world", sunk costs can be understood to inherently capture certain of these effects. Nonetheless, we as economists, may face grievous difficulties in measuring and identifying such effects of sunk costs, due to the inherent information losses to economic systems, which constitute a form of market failure, associated with such unanticipated economic shocks. In light of this market failure, there is a major limitation to eventual econometric approaches, which naively tend to extrapolate from existing models, since these may not reflect underlying adjustment mechanisms associated with unanticipated shocks.

In light of the analysis of this paper, it can be noted that even the simple multiplier calculations that are part of comparative static analysis in introductory economics course can be viewed as misleading if one admits the possibility of frictions in adjustment processes due to underlying sunk costs. The latter can redefine the fundamental structure of economic mechanisms and relations such that naïve derivative calculations based on an ex ante model can turn out ex post to be quite misleading since such methodology obfuscates the very processes that it is seeking to explain.

The analysis presented here gives a center stage role for sunk costs in understanding a wide range of economic phenomenon, while emphasizing that existing understandings of the role of such sunk cost effects are often fundamentally flawed. Undoubtedly, one reason for the existing fallacies regarding sunk costs is that little if any attention has been given to the point of discontinuity between *ex ante* and *ex post* roles for sunk costs. Such approaches fail to realize how the frontiers of economic analysis have been severely handicapped by a reliance on analytical tools which actually have imbedded assumptions regarding the role of such sunk cost effects. In the big bang of transition from p=0 to p=1, there is most certainly a role for the associated effects on agents' expectations and optimizing behavior, in scenarios where the world does not

instantaneously adjust and there are effects of hysteresis, which correspond to historical givens that can critically matter. To paraphrase a quote from Robert Frost: "Two paths diverged in a wood and I thought about "taking the one least traveled by", but there was an external shock, so that I ended up on yet another path and "that has made all the difference." From an economic standpoint it is not just "character that is fate", the past matters in complex ways, which depend on sunk costs, which are a form of economic mutation. In sum, like the emperor, when it comes to the proper specification and consideration of sunk costs, much of existing economic analysis "has no clothes".

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