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Technological Change as a Monetary Phenomenon

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This article attempts to study the function of monetary systems as networks of communication, which facilitate the channelling of social effort in the presence of exogenous conditions. A model of monetary system is being proposed, where monetary balances are algorithms of response, built up in the presence of uncertainty induced by technological change. Empirical research brought in support to that model demonstrates a strong and negative correlation between the velocity of money and the share of aggregate depreciation in current output, with intriguing links to exogenous mechanisms of energy absorption in the local social system.

Keywords: monetary systems, technological change

Introduction

The theory of money and finance systematically turns around the more or less explicit assumption that financial markets are inherently unstable. Seminal contributions in that direction of research start with Adam Smith, who claimed that lack of prudence in the issuance of currency can destabilize an economy. The now classical development by Kindleberger and Aliber (2005) points at an interesting pattern of contradiction in economic history: although financial crises are always perceived, at the moment, as instances of deep disequilibrium, their recurrence suggests, strangely enough, that they are a symptom of some long-term equilibrium, which we do not exactly understand. Another seminal contribution, from Minsky (1992), suggests that we should always assume that financial markets are unstable and volatile: this is just safer for economic policy. That stream of literature seems to focus on short-term reactions of economic agents to financial stimuli, and tends to assume that the short-term reactions are the only relevant ones. Yet, another theoretical view can be coined from the available literature. The quite convincing developments of post-Keynesianism, especially those coming from Modigliani (see, for example: Modigliani & Brumberg, 2005; Ando & Modigliani, 1963) suggest that in the long-term perspective of a life-cycle, where economic agents have the time and the motivation to correct their line of action, short-term financial decisions sum up to a very rational adaptation to the economic environment. Thus, a general theoretical question can be formulated: is the observable instability of financial markets just an instability, or is it, in fact, the symptom of a deeper, long-term process of imperfect adaptation in the economic system as a whole?

Data published by the World Bank allow observing a systematically decreasing velocity of money in the global economy[1]. Under the category labelled "World", the statistic provided by the World Bank allows calculating an aggregate, global velocity of money at the level of V = 1.85 in 1962. In 1972, that global

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[1] https://data.worldbank.org/indicator/FM.LBL.BMNY.GD.ZS.

velocity falls to V = 1.511, to reach V = 0.849 in 2014, and V = 0.815 in 2015. Money is slowing down.

Technological change is a major source of uncertainty, as it is a significant factor of social change. Technologies interact with social structures in a loop of mutual influence, which, in turn, is not necessarily a straight path of progress. Since the seminal metaphor of struggling civilisations, in Toynbee's (1946) *Study of History*, the idea of developmental leaps seems to have gained some grounds. Edgerton (2011), points out that the assumption of constant technological progress is rather an illusion than a hard fact. Technological change as a process, which supposedly brings consistent improvement in the conditions of living, seems not to exist. Technological change can have really a disparate relation with technological progress. According to David Edgerton's findings, there were just a few periods of real technological progress since 1900: between 1900 and 1913, followed by another between 1950 and 1973. Save for those short windows in time, the link between technological change and the conditions of living is really ambiguous. Probably since the works of Karl Marx, the mutual interaction between technology and society tends to be described through various intellectual stances regarding the general hypothesis of technological determinism, i.e. the claim that it is technology that bends social reality around itself, with social structures being quite passive in the process (see for example: Mumford, 1964; McKenzie, 1984; Kline & Pinch, 1996). Some research suggests that we are talking about an interaction full of bends and turns, far from being fully logical and straightforward (see: David, 1990; Vincenti, 1994). Still, some clear patterns are identifiable in this interaction. Technologies can truly and deeply transform social structures when they have the capacity to simplify themselves for their end-users (see Mahoney, 1988), whilst creating an increasing complexity inside themselves (Ceruzzi, 2005).

As social change is considered, a range of other facts is to mention. Since 2008, the world of finance has witnessed the turbulent development of the phenomenon called "cryptocurrencies" or "Blockchain currencies". Bitcoin is probably the elder in the family, and the best known, but the world of cryptocurrencies comprises today over 800 different ones, although just some 620 have any significant market capitalization (see, for example: www.coinmarketcap.com or www.bitinfocharts.com). In very crude term, the probability that a new cryptocurrency emerges somewhere in the world is some four times greater than the probability of seeing a new national currency. Cryptocurrencies display those peculiar characteristics, which, fault of a better term, can be called "proto-money". They are legal claims, combining the traits of speculative assets with those observable in money strictly spoken. Their balances can both offer opportunities of speculative profit, and serve to settle accounts. The technology of cryptocurrencies, or the Blockchain, is very similar, in its logic, to the institution of endorsement, invented at least as far back in the past as the 12th century, for allowing the circulation of bills of exchange.

As the global economy creates more and more money per unit of real output, experimentation with new types of money emerges as another trend, as if the global economy needed more money. What does it need money for? Penn Tables 9.0 (Feenstra, Inklaar, & Timmer, 2015) bring two interesting insights in that respect. Firstly, aggregate depreciation of fixed assets, when corrected for national purchasing power parities, makes a growing proportion of the national GDP, across the 182 national economies surveyed in the database. In 1980, aggregate depreciation made, on average, 9.5% of a national GDP. In 2000, that ratio climbed to 12.8%, to reach 18.6% in 2014. Interestingly, when the same depreciation is calculated without correction for purchasing power, just at current national prices of assets, converted into constant 2011 US dollars, the trend looks different: it becomes bell-shaped, with its belly the most protruding upwards during the 1980ies, around 20%, and currently at 18%. It looks as if, over the last six decades, a long-term, inflationary pressure on the prices of fixed assets had taken place. Anyway, when related to purchasing power, the national income of most countries has less and less capacity to compensate the obsolescence of their fixed assets.

Against the dominant background of the classical monetarism, there is a stream of thought, known since, at least, the 17th century and the principles of mercantilism, which claims that money can be an autonomous social force, and not just a medium of payment. Contemporarily to Adam Smith, Joseph de Pinto engaged in a long-lasting (and probably life-endangering) polemic with Marquis de Mirabeau, arguing that creation of money, also indirectly, via the development of markets for public debt, can be an autonomous force facilitating progress and social well-being (see: De Mirabeau, 1760; Pinto, 1771). A much more modern contribution in that respect had been made by Samuelson (1958), who suggested that money can be a social contrivance, serving to transfer value not just in space, but also in time. Against the dominant assumption that money loses value over time, Samuelson proposed a theoretical network for studying money as a technology serving to transmit accumulated value between generations. The theoretical framework proposed by Paul Samuelson rests on a central assumption that the supply of money can and should increase at a basic rate closely correlated with the rate of demographic growth.

At any given moment, there are three generations of technologies in use: emergent, established, and declining. The pace of technological change can be seen as the proportion between the relative diversity (or simply the sheer number) of technologies available in each of those generations. The more are there emergent technologies, the greater is the pressure on the obsolescence of the established ones, thus on their transition to the declining generation. If the diversity in emergent technologies, thus, for example, the propensity to patent new inventions, grows systematically, an increasing pressure towards obsolescence appears. The greater is that obsolescence, and the faster is the pace of replacement, in the world of technologies, the greater amount of capital is needed to finance the process. At this point, it is useful to remember that the supply of money is, and historically has always been the supply of account money, not cash money (see for example: Braudel, 1979-1981; 1979-1983). Both presently, and historically, the greatest amounts of money have been created to settle intangible capital accounts, not to pay for tangible things. From the practical point of view, money is needed mostly and primarily to assure liquidity in balance sheets, and only secondarily in the markets of goods and services. In other words, when technological change accelerates, it could lead, through increased depreciation and compensatory behaviour from the part of entrepreneurs, to the swelling of balance sheets, and to a correspondingly growing demand for money. Wrapping all the above, reasoning up leads to the hypothesis that there is a significant, negative correlation between the pace of technological change, as measured by the pace of depreciation in fixed assets, and the velocity of money.

The Model

The theoretical model of this article starts with the monetary quantitative equilibrium, namely: $P*T = M*V$. It is being argued that such quantitative equilibrium can occur only when the monetary mass present in the system is close to that required by Keynesian equilibrium, i.e. with no speculative money (Keynes, 1937-2007). From here on, the article develops on the idea that financial markets are essentially systems of communication, which facilitate the coordination of social effort in large social structures, difficult to coordinate through political systems or basic human contact. The most fundamental hypothesis behind this idea is that the relative size of financial markets, i.e. their size denominated in real output of the economy, is significantly determined by the amount of uncertainty, actually experienced by social agents. Uncertainty is experienced as the number of alternative strategies, mutually equivalent in their expected payoffs. This is an extended version of the classical Nash's dynamic equilibrium (see for example: Nash, 1951). Nash assumed that dynamic equilibrium in a game can be achieved only on the grounds of the so-called dominant strategies, i.e. strategies that offer the best possible payoff to their respective players. Whilst Nash assumed there is just one dominant strategy in each player at a given moment, the present article assumes that, in the presence of quick social change, social agents can face a irreducible multitude of equiprobably dominant strategies. This assumption is essentially based on the work by Herbert W. Simon (1956). In the presence of such uncertainty, social agents can develop many alternative algorithms of response to the possible contingencies, by building the reserves of immediately available resources.

Technological change induces disequilibrium and uncertainty. The degree of uncertainty is observable as the number of alternative technologies that entrepreneurs can invest their capital in, at a given moment. Those up-coming technologies push the established technologies out of use. The process of technological obsolescence is being anticipated by entrepreneurs, and this anticipation is observable as the official depreciation, accounted for in fixed assets. Whilst the depreciation of physical capital is technically calculated in the base of this capital, in business practice it is a fraction of the current income—thus current output—which has to be used for implementing new technologies in the place of the established, obsolete ones.

Two alternative states of that general process can be defined, according to the degree of uncertainty. There is a hypothetical state of equilibrium, akin to the Nash's dynamic equilibrium, where the majority of entrepreneurs can develop dominant strategies regarding the investment in new technologies. These dominant strategies consist in focusing investment on clearly defined, new solutions, and they can be developed as long as the pace of turnover in technologies does not exceed a critical threshold. Past that threshold, the number of new technologies, upcoming and possible to implement, creates a growing uncertainty as for which new technology is the best investment. In the presence of such uncertainty, entrepreneurs develop their strategies as less and less dominant ones, i.e. each plan of investing in new productive assets is being accompanied by a proverbial plan B, assuming a different direction of investment. Each plan B requires to secure a certain amount of capital "just-in-case", both as fixed assets (e.g. patents) with problematic immediate utility, and as liquid assets, monetary balances included. As the pace of technological obsolescence increases, more and more uncertainty is being provided for, in entrepreneurial strategies, observable at three levels, as: a) a growing share of depreciation in the current output; b) a growing amount of fixed assets in relation to current output; and c) growing nominal value in monetary balances. At this level of uncertainty, some kind of Nash's dynamic equilibrium can be formed on the grounds of dominant strategies in individual entrepreneurs, even if each dominant strategy comes along with an ace up one's sleeve. Another threshold of uncertainty occurs, when the "B plans" become so numerous that no dominant strategy can be defined by any entrepreneur. Hence, no Nash's dynamic equilibrium can be defined, and the solution to the market game lies, by definition, outside the game. This is super-fast technological change, which induces the build-up of extremely valuable monetary balances (as well as balances of other liquid assets), and a quick fall in the velocity of money.

At a given moment "t", economic agents face set of n new, upcoming technologies NTC(t) = {ntc1, ntc2, ..., ntcn}. At any given moment, the observable value of n can fall above or under a threshold n_u, which symbolizes the number of new technologies that starts inducing that critical uncertainty. Equation (1), below, summarizes the above. In the presence of new technologies coming in a number below the uncertainty-inducing level (i.e. $n < n_u$), incremental change in the velocity of money is null or positive (i.e. velocity is constant or decreasing <=> $dV \geq 0$), whilst the share of aggregate depreciation in current output is constant or decreasing, and thus its first moment is null or negative. In this hypothetical state, monetary balances do not have much to do in terms of transferring capital from old technologies to the new ones, as the pace of technological change allows clear focusing of investment strategies. As the number of new, upcoming technologies passes the threshold "nu" of uncertainty, the economic mechanism changes. The relative burden of aggregate depreciation in relation to current output increases, thus its first moment is positive (i.e. $d\left({}^{D}/_{Q}\right) > 0$). Entrepreneurs start providing for uncertainty induced by technological change, and they build up monetary balances of the "just-in-case" type. The whole pattern is accompanying by the general assumption, expressed in equation (2), further below, namely that the overall variance, observable in the velocity of money "V", is a linear function of the variance observable in the "D/M" ratio, or, in other words, in the value of aggregate depreciation, denominated in the units of monetary mass.

$$dV = \begin{Bmatrix} n < n_u; & dV \geq 0; & d\left({}^{D}/_{Q}\right) \leq 0 \\ n \geq n_u; & dV < 0; & d\left({}^{D}/_{Q}\right) > 0 \end{Bmatrix} \tag{1}$$

$$var(V) = a * \left[var\left({}^{D}/_{M}\right)\right] + Res\_var \tag{2}$$

Empirical Check

The dataset used for empirical research in this article is a compound one, based on Penn Tables 9.0 (see: Feenstra et al., 2015), appended with selected data published by the World Bank, mostly regarding the supply of money. The so-compiled database allows observing a process of change in the velocity of money, taking place in the background of the previously mentioned, global decrease in said velocity. While the global metric (i.e. global real output divided by the global supply of broad money) has been following, since 1960, an unequivocally descending trend, the cross-sectional average of local velocities, observable in national monetary systems, displays a slightly different picture. The overall, long-term way downwards had been disrupted, between 1972 and 1990, by a sudden surge, followed by just as sharp a fall. Figure 1 shows this interesting phenomenon, which looks as if national monetary systems, in the 1970ies and 1980ies, suddenly had gotten rid of some monetary balances, just to rebuild them immediately after, at an accelerated pace. This is the red continuous line in Figure 1, below. Following the general theoretical intuition of this article, a second variable is being added in Figure 1: the average share of aggregate depreciation in the national GDPs of countries reported in Penn Tables 9.0. In order to achieve graphical clarity, both metrics, namely the average velocity of money, and the average share of depreciation in the GDP, are presented as indexes with constant a base, pegged in 2000. Putting them back to back, together in one graph, suggests that, in the long run, a greater burden of provisions for the obsolescence of technologies is correlated with a lower velocity of money, with, somewhere on the road, that intriguing window of something that looks as intensified experimentation in national monetary systems. If we take the actual, non-indexed values of those variables, they are Pearson-correlated ATR = -0.624886149: the greater the expected share of aggregate depreciation in the GDP, the lower the expected velocity of money. Why "expected"? Because we are talking about cross-sectional averages between national economies. One of the most fundamental assumptions of statistics is that an arithmetical average is the expected value in a set of observations.

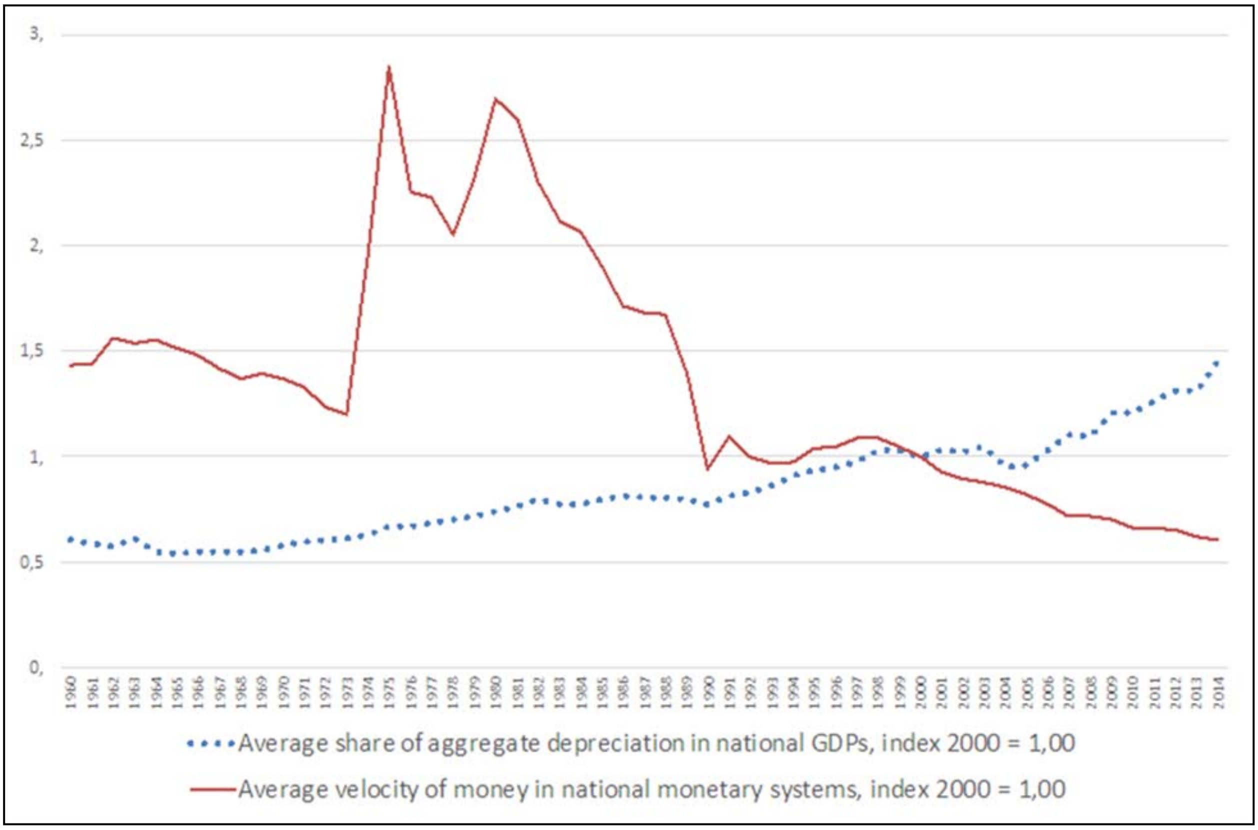

Figure 1. Average velocity of money in national monetary systems, and average share of aggregate depreciation in national GDPs, in the sample of countries in Penn Tables 9.0. Source: Penn Tables 9.0, World Bank.

For each year since 1960 through 2014, the cross-sectional variability in the velocity of money can be calculated, as the ratio of cross-sectional standard deviation in velocity, divided by the mean velocity. This ratio of variability can be considered as a metric of relative disparity among national monetary systems. In Figure 2, below, it is shown as the continuous, clear line. Between 1972 and 1990, across the sample of countries reported by the World Bank[2], the spatial differentiation in the velocity of money experienced a sudden surge. During those 18 years, national monetary systems in the world suddenly drifted apart from one another, regarding the velocity of money. This disparity, which ended as suddenly as it started, can be interpreted as a period of intensified experimentation in national economies. The question is, what kind of experimentation could it have been? There, another metric calculated in the author’s compound database comes as informative: the ratio of aggregate depreciation in the GDP. Penn Tables 9.0 originally provide an average rate of depreciation in fixed assets, in the classical way, as percentage of the fixed capital available. This rate and its capital base can be multiplied, to produce aggregate depreciation in the given country and year. Aggregate depreciation, in turn, can be interpreted as the amount of capital, which has to flow from older technologies, being replaced, to the new ones, coming to supplant them. It can be reasonably assumed that such a flow of capital takes the form, momentarily, of a monetary aggregate, or, in other words, a set of monetary balances.

[2] https://data.worldbank.org/indicator/FM.LBL.BMNY.GD.ZS.

Therefore, in arithmetical terms, it can be interesting to track the share of aggregate depreciation in the aggregate supply of money. This particular ratio, namely "aggregate depreciation divided by the aggregate supply of money", can be calculated for each country and year separately, and, just as for the velocity of money, a rate of cross-sectional variability can be computed. This particular spatial variability is shown in Figure 2 as the dark-blue, dotted line. It shows a striking similarity to the cross-sectional variability in the velocity of money. As a matter of fact, those two time-series yield a Pearson correlation of r = 0.988042182.

As Figure 2 traces complex metrics, which are ratios of cross-sectional variability in other ratios, some conceptual simplification can be useful. Both metrics, in which cross-sectional variability has been computed, annually, since 1960 through 2014, are, in fact, very similar economically and mathematically. The velocity of money is computed as $V = Q/M$, or as the ratio of aggregate output divided by the aggregate supply of money. Now, if we replace, in the nominator, the aggregate output of the national economy with the aggregate depreciation of fixed capital, we obtain the second metric, or D/M. These two metrics are simply distinct economic aggregates, denominated in the same units, i.e. in the units of monetary mass. In other words: the clear continuous line shows the momentary disparity between national monetary systems, whilst the dark-blue, dotted line shows the analogous, momentary disparity between national economies as for the effort that those monetary systems have to make in order to channel capital from older technologies to the new ones. Table 1, provides the detailed means and variances that served to compute the ratios of variability traced in Figure 2.

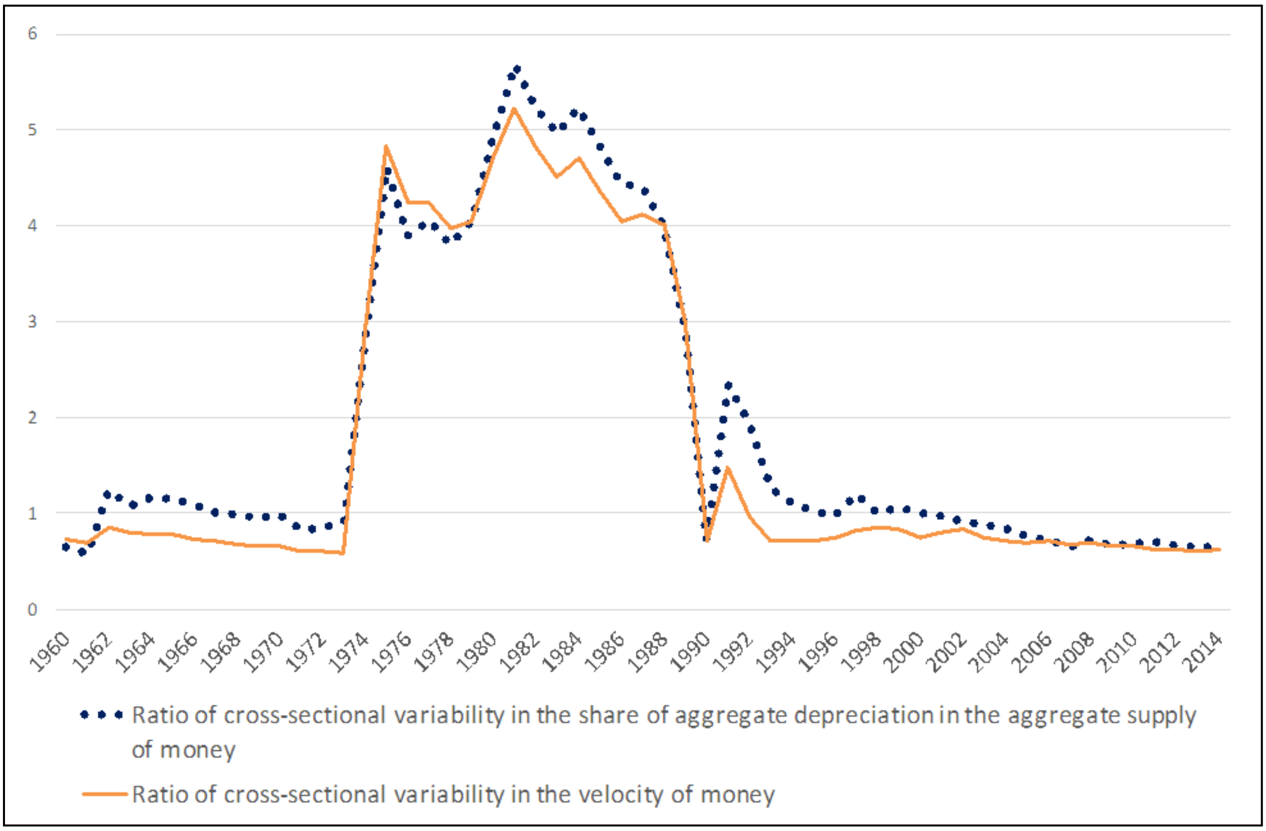

Figure 2. Correlation between: a) the cross-sectional variability in the share of aggregate depreciation in the monetary mass and b) the cross-sectional variability in the velocity of money. Source: author's.

Table 1
Means and Cross-Sectional Variances in, Respectively, the Share of Aggregate Depreciation in the Aggregate Supply of Money, and in the Velocity of Money.

Year	Average, national share of aggregate depreciation in the aggregate supply of money	Cross-sectional variance in the share of aggregate depreciation in the aggregate supply of money	Ratio of cross-sectional variability in the share of aggregate depreciation in the aggregate supply of money	Average, national velocity of money	Cross-sectional variance in the velocity of money	Ratio of cross-sectional variability in the velocity of money
1960	0.352	0.051	0.641975589	4.427	10.342	0.726421663
1961	0.343	0.04	0.582408419	4.442	9.72	0.701881619
1962	0.398	0.24	1.228741806	4.826	16.734	0.847699934
1963	0.377	0.165	1.074608577	4.734	14.122	0.793779326
1964	0.368	0.182	1.158980656	4.79	14.23	0.787463224
1965	0.347	0.158	1.145296546	4.664	13.107	0.77617136
1966	0,341	0.142	1.102229345	4.581	11.434	0.738226452
1967	0.328	0.109	1,007854571	4.381	9.632	0.708450288
1968	0.312	0.094	0.982946075	4.227	8.149	0.675356183
1969	0.315	0.089	0.945159856	4.288	7.854	0.653596781
1970	0.319	0.099	0.989308209	4.227	7.764	0.65921065
1971	0.309	0.066	0.8344618	4.089	6.157	0.60683884
1972	0.287	0.058	0.838124283	3.809	5.304	0.604581435
1973	0.282	0.066	0.913035431	3.713	4.754	0.587285378
1974	0.435	1.452	2.768551256	6.11	323.321	2.943010938
1975	0.675	9.675	4.61053319	8.781	1,794.473	4.824175165
1976	0.532	4.281	3.889026827	6.954	865.69	4.231250992
1977	0.555	5.058	4.053132343	6.88	850.193	4.238069725
1978	0.538	4.164	3.793628344	6.328	631.509	3.971127311
1979	0.616	6.215	4.048230086	7.137	829.63	4.035855964
1980	0.778	14.505	4.898324509	8.311	1,543.371	4.726898088
1981	0.848	23.069	5.666059837	8.015	1,742.,964	5.208716225
1982	0.761	15.8	5.22473091	7.106	1,162.753	4.798540747
1983	0.673	11.153	4.959126205	6.523	861.234	4.499194953
1984	0.673	12.403	5.232768689	6.377	901.336	4.707557041
1985	0.591	8.085	4.811176951	5.859	653.117	4.361678372
1986	0.534	5.599	4.434373006	5.291	457.528	4.042561189
1987	0.505	4.892	4.381136566	5.197	457.628	4.115909544
1988	0.484	3.759	4.004415001	5.156	428.104	4.012745282
1989	0.388	1.256	2.887965477	4.296	167.519	3.012761472
1990	0.265	0.037	0.723749926	2.912	4.369	0.71790304
1991	0.357	0.696	2.339910406	3.37	25.068	1.485728642
1992	0.332	0.42	1,952022258	3.074	8.777	0.963710473
1993	0.322	0.162	1.247602771	2.974	4.54	0.716316823
1994	0.345	0.148	1.117123172	3.022	4.683	0.716096608
1995	0.373	0.146	1.027088741	3.212	5.315	0.717625932
1996	0.363	0.124	0.968615542	3.228	5.827	0.747785533
1997	0.391	0.221	1.202851733	3.35	7.515	0.818394923
1998	0,383	0.151	1.013669538	3.366	8.125	0.846712511
1999	0.375	0.16	1.067687832	3.24	7.196	0.828035758

(Table 1 continued)

Year	Average, national share of aggregate depreciation in the aggregate supply of money	Cross-sectional variance in the share of aggregate depreciation in the aggregate supply of money	Ratio of cross-sectional variability in the share of aggregate depreciation in the aggregate supply of money	Average, national velocity of money	Cross-sectional variance in the velocity of money	Ratio of cross-sectional variability in the velocity of money
2000	0.352	0.125	1.005188144	3.085	5.336	0.748699646
2001	0.315	0.092	0.963830383	2.857	5.325	0.807752413
2002	0.298	0.074	0.913525643	2.771	5.412	0.839526415
2003	0.3	0.07	0.883533426	2.719	4.144	0.748824267
2004	0.291	0.06	0.840355385	2.64	3.579	0.716728221
2005	0.288	0.047	0.756415922	2.551	3.212	0.702647056
2006	0.282	0.041	0.716455947	2.388	2.837	0.705141424
2007	0.269	0.031	0.658260589	2.212	2.242	0.676714799
2008	0.285	0.042	0.714953963	2.227	2.392	0.69457578
2009	0.297	0.039	0.670064375	2.176	2.107	0.666953892
2010	0.284	0.037	0.67677319	2.047	1.837	0.662181567
2011	0.302	0.045	0.703668678	2.044	1.624	0.623310352
2012	0.302	0.041	0.673627194	2.015	1.584	0.624460155
2013	0.299	0.039	0.658748394	1.93	1.383	0.609435227
2014	0.297	0.038	0.65453325	1.871	1.337	0.618185206

Source: Penn Tables 9.0, World Bank.

Carrying the empirical investigation one step further, the two basic ratios, whose cross-sectional variabilities are traced in Figure 1, have been subject to linear regression. Regression served to test the general hypothesis that the amount of money needed to provide for aggregate depreciation of fixed capital is significantly correlated with the velocity of money. The same, compound database made of Penn Tables 9.0, enriched with data from the World Bank, has been used to run Ordinary Least Squares, linear regression in a data panel of natural logarithms of empirically observable values[3]. The temporal frame was the same as that shown in the graph, namely since 1960 through 2014. The first step in the analysis of regression consisted in testing the most basic equation, namely: $\ln(V) = a \times \ln(D/M) + b$. The test, run on a total sample of n = 4,395 country-year observations, yielded a coefficient of determination $R^2 = 0.506$, and the following empirical parameters: $\ln(V) = 0.739 \times \ln(D/M) + 1.967$. The standard error of the “a” coefficient was SE(a) = 0.018, and the corresponding correlation was T-significant at $p < 0.001$. The constant term “b” yielded a standard error equal to SE(b) = 0.023, at T-significance $p < 0.001$.

In the second step, the otherwise quite substantial residual term obtained in the first regression has been tested for its correlation with other variables in the database. The logic behind this step of investigation was that variables significantly correlated with said residual can be mediating between the velocity of money and the monetary equivalent of aggregate depreciation. A range of variables has been thus identified, and multiple linear regression has been performed on their natural logarithms, as for their explanatory power in mediating between the velocity of money, and the ratio D/M. These variables are: a) energy use per capita, in kilograms of oil equivalent; b) GDP per capita; c) the ratio of fixed capital divided per GDP (CK/Q); d) the share of

[3] The use of natural logarithms served to provide, at least partly, for different non-stationarities observable in the 1960-2014 time-series in individual countries of the database.

households' consumption in the GDP (C/Q); e) the ratio of resident patent applications per one million people; f) depth of the food deficit, in kilocalories per person per day; g) urban population as % of total population; and h) the share of central government's spending in the GDP (GOV/Q). Tables 2 and 3, summarize the results of that multiple regression. A methodological remark is due before the properly spoken interpretation of those results. Among the variables correlated with the residual from the first regression, the depth of food deficit, in kilocalories per person per day, as published by the World Bank, is to find. This variable is explicitly given only for countries, when malnutrition is officially reported (it is the total alimentary deficit of all the people classified as malnourished, spread over the total population). With food deficit on the right side of the expanded equation, the dataset used by the author yields just n = 494 valid country-year observations. Although this small subsample of the total database yields a highly informative function, explaining more than 94% of the variance observable in the velocity of money (R^2 = 0.948), this specific subsample contains only observations from developing countries and some from emerging markets. The developed economies are de facto absent from this particular regression. Thus, the extended regression is presented in two versions: Table 3, presents the results of regressing the velocity of money on all the variables identified, thus the small subsample mentioned above, whilst Table 2 introduces an enlarged panel of observations (n = 2184; R^2 = 0.933) obtained after excluding food deficit from the equation. Coefficients in Table 2 can be interpreted as a general case, containing all types of economies.

Table 2

Coefficients of the Empirical Model, Where the Explained Variable Is the Velocity of Money; Model Without the Food Deficit; N = 2184; R^2 = 0.933

Explnanatory variable	Coefficient	Std. error	T-statistic	*P*-value
ln(D/M)	0.944	0.008	121.955	0.000
ln(Energy use (kg of oil equivalent per capita))	0.038	0.01	3.751	0.000
ln(GDP per capita)	-0.056	0.01	-5.786	0.000
ln(CK/Q)	-0.695	0.014	-50.326	0.000
ln(C/Q)	0.259	0.022	12.017	0.000
ln(Patent applications, residents per 1 million people)	-0.025	0.003	-7.643	0.000
ln(Urban population as % of total population)	0.189	0.02	9.286	0.000
ln(Gov/Q)	0.073	0.01	7.354	0.000
Constant	3.42	0.081	42.054	0.000

Source: author's.

Table 3

Coefficients of the Empirical Model, Where the Explained Variable Is the Velocity of Money; Model Including the Food Deficit; N = 494; R^2 = 0.948

Variable	Coefficient	Std. error	T-statistic	*P*-value
ln(D/M)	0.964	0.016	60.828	0.000
ln(Energy use (kg of oil equivalent per capita))	0.128	0.016	8.054	0.000
ln(GDP per capita)	-0.197	0.024	-8.221	0.000
ln(CK/Q)	-0.83	0.027	-30.747	0.000
ln(C/Q)	0.097	0.043	2.258	0.024
ln(Patent applications, residents per 1 million people)	-0.033	0.004	-8.186	0.000
ln(Depth of the food deficit (kilocalories per person per day))	0.037	0.008	4.9	0.000
ln(Urban population as % of total population)	0.547	0.026	20.938	0.000

(Table 3 continued)

Variable	Coefficient	Std. error	T-statistic	*P*-value
ln(GOV/Q)	-0.011	0.026	-0.431	0.667
Constant	3.967	0.171	23.261	0.000

Source: author's.

The mediating variables, identified as correlated with the residual component in the first, simple regression, are logically coherent with the model presented earlier in this article, although they very largely cancel their respective impacts. As a result, both the coefficient ascribed to ln(D/M), and the residual constant in the multiple regression, are greater than those obtained in the simple one. The mediating variables of the extended equation seem to explain an additional portion of variance in the velocity of money, without changing its essential correlation with the monetary expression of aggregate depreciation. Interestingly, in the general case (Table 2), three mediating variables come as most potent in their impact: the ratio of fixed capital divided by the GDP, the share of consumption in the GDP, and the share of urban population in the total headcount. The stock of physical capital present in the given country, at a given moment, is negatively correlated with the velocity of money. The more units of real output are being "frozen" as fixed assets, the more units of real output are being monetized. Thus, the pattern identified in this multiple regression is that of national economies maintaining some sort of constant liquidity regarding their physical assets. Each unit of output immobilized in fixed assets seems to need a counterpart in the form of monetary balances. This, in turn, seems to confirm the hypothesis of said monetary balances serving as algorithms of response in the presence of uncertainty induced by technological change. The share of consumption in the GDP acts in the opposite way: it favours a greater velocity in the monetary mass, thus less money supplied per each unit of real output. This particular result seems counterintuitive at first sight. More real output being subject to current consumption should result in a greater demand for money in relation to the GDP. Still, the results are there: it is exactly the opposite. The third major explanatory factor in the general case is the rate of urbanization. Its positive coefficient in the multiple regression is probably the most coherent of the three: the more people live in urban settlements, the greater the average density of population, which, in turn, creates more social interactions and a faster circulation of the monetary mass.

As the general case that the incidences of food deficit get truncated down in the developing countries and emerging markets (Table 3), the parameters of the extended equation change interestingly. The ratio of physical capital divided by the GDP (CK/Q), and the rate of urbanization hold their positions still in the explanation of the velocity of money, but other factors come to the first plan: energy use per capita, and GDP per capita. They seem to push aside, in terms of explanatory power, the relative weight of consumption in the GDP. The more energy is being consumed per capita in countries with observable pockets of malnutrition, the greater the velocity of money. More energy consumed seems to imply less monetary mass necessary to finance the circulation of real output. By comparison with the general case, we can guess the presence of some satiation threshold, regarding the use of energy per capita. Below that threshold, technological change observable as the pace of depreciation in established technologies, is strongly correlated with a greater consumption of energy. This is the type of technological change, where technologies get simply stacked together, and the stacking results in greater energy use. Past this threshold, technological change might be more of a reshuffling in the portfolio of technologies used. The ratio of GDP per capita seems to slow down significantly the circulation of monetary mass, in this special case. The provisional explanation for this particular result comes from general economic knowledge: the wealthier people are, in terms of GDP per capita, the greater part of their disposable income is being saved, thus building very slowly circulating monetary balances.

Table 4, shows the results of one more regression test, which served as some sort of robustness check. The two main variables, on the two sides of the equation, are: velocity of money, or real output denominated in units of monetary mass (V = Q/M), and aggregate depreciation, denominated, as well, in units of monetary mass (D/M). With the same denominator on both sides, it seems reasonable to put the nominators back to back. We already have, in the extended equation, one variable denominated in units of real output, namely the "CK/Q" ratio of physical capital divided by GDP. Following the underlying logic of that variable, the ratio of aggregate depreciation divided by GDP, or "D/Q" is added (or rather its natural logarithm) to the test of regression. The so-obtained model offers some interesting insights. With n = 2,184 country-year observations, it yields a coefficient of determination $R^2 = 0.989$, thus relatively the highest of the three. Interestingly, with ln(D/Q) in the equation, the residual constant plummets by one order of magnitude, just as the coefficients of other variables do, as if ln(D/Q) absorbed some of this overall variance. The coefficient of ln(D/Q) is almost exactly symmetrical to that of ln(D/M): big and negative. The more aggregate depreciation in relation to real output, the lower the velocity of money.

Table 4

Coefficients of the Empirical Model, Where the Explained Variable Is the Velocity of Money; Model Enriched With the Share of Aggregate Depreciation in the GDP (D/Q); N = 2.184; $R^2 = 0.989$

Variable	Coefficient	Std. error	T-statistic	*P*-value
ln(D/M)	0.985	0.003	358.244	0.000
ln(Energy use (kg of oil equivalent per capita))	0.031	0.004	8.157	0.000
ln(GDP per capita)	-0.007	0.005	-1.503	0.133
ln(CK/Q)	-0.029	0.006	-4.443	0.000
ln(C/Q)	0.1	0.014	7.224	0.000
ln(Patent applications, residents per 1 million people)	-0.006	0.001	-5.081	0.000
ln(Urban population as % of total population)	0.035	0.006	5.488	0.000
ln(Gov/Q)	0.027	0.004	6.052	0.000
ln(D/Q)	-0.918	0.01	-91.266	0.000
Constant	0.171	0.053	3.227	0.001

Source: author's.

Conclusion

The pace of technological change can be represented as the intensity of depreciation in the fixed assets of an economic system. Significant changes in that intensity come from the variation of moral obsolescence in the technologies used, much more likely than from varying a physical wear and tear of material objects. If we hypothesise, for a moment, that economic systems build monetary balances as algorithms of response in the presence of the expected obsolescence in established technologies, aggregate depreciation can be denominated in two distinct bases: the real output of the economy, on the one hand, and the units of monetary mass, on the other hand. There is substantial evidence that the more aggregate depreciation we have in relation to current output, the slower is the circulation of money, or, in other words, the more speculative monetary balances are being built as a provision for uncertainty induced, in turn, by the pace of obsolescence in established technologies. Solid empirical case can be made, as well, for claiming that the greater is the share of aggregate depreciation in the overall monetary mass, the greater the velocity observable in said mass. The way that technological change occurs in real output seems significantly correlated with monetary phenomena. Technological change can be studied as a monetary phenomenon, and changes in monetary systems can be largely attributed to the impact of technological change.

The ratio “D/M”, or aggregate depreciation divided by the aggregate supply of money, can be observed as for its expected, average trend, as well regarding its cross-sectional idiosyncrasy. The ratio “D/M” shows a strong and positive correlation with the velocity of money, which, in turn, represents real output denominated in the units of monetary mass (Q/M). This correlation took a peculiar, intriguing turn between 1972 and 1990. During that window of eighteen years, national monetary systems suddenly became highly idiosyncratic in their velocity of money, and this surge in diversity came along with just as sudden a surge in cross-sectional disparity of locally generated, aggregate depreciation. The whole episode, as deconstructed in this article, looks very much like a period of particularly intense learning through experimentation, preceded and followed by significantly lesser a propensity to experiment. Interestingly, that window in recent economic history corresponds to the rise of monetarism as a dominant ideology in economic policy. The preceding period of a much lower spatial disparity (i.e. since 1960 to 1970) was the era of Keynesianism, and what followed was the domination of the so-called New Consensus in Macroeconomics. A question at the limit of economics and hermeneutics arises: was the theory of monetarism a cultural verbalisation of intense experimentation in monetary systems, in response to a sudden surge in uncertainty connected to technological change? This question remains open for further discussion.

There is a complex link between the pace of technological change, observed as aggregate depreciation, and the velocity of money. The more aggregate depreciation in relation to real output, the more money is being held in the monetary system, and the lower the velocity of money. Still, the more aggregate depreciation in relation to the aggregate supply of money, the greater the velocity of money. A tentative theoretical explanation can be formulated, to explore in further research. We can imagine a process of adaptation at two levels, in the monetary system. Firstly, as the pace of technological obsolescence accelerates, and as uncertainty induced by said obsolescence increases, economic agents hoard more monetary balances to provide for that uncertainty. Secondly, the build-up of those “just-in-case” monetary balances can display various dynamics. It can be really fast, and the supply of money can grow faster than aggregate depreciation. It can be moderate, and then both aggregates advance side by side, with the “D/M” ratio more or less constant. Finally, the monetary system can stay largely indifferent to changes in aggregate depreciation, with a decreasing ratio “D/M”. Empirical research presented in this article suggests that the process in question is largely correlated with the accumulation of physical capital in relation to current output, as well as to the ways that national income is being spent on the current basis, both in households and in the public sector. Intriguing ramifications of that general process appear in connection to the level of wealth, observable qualitatively, as the distinction between the presence or the absence of starvation. If we select, from the general sample observed, just the economic systems with observable malnutrition in their populations, thus with officially reported food deficit, the consumption of energy per capita becomes a significant correlate, whilst household consumption loses much of its impact in the process. Still, at the end of the day, and even with all the mediating variables taken into account, we return to the fundamental tension between three processes: the accumulation of physical capital in relation to current output, the technological obsolescence of the corresponding fixed assets, and the relative speed of building up monetary balances in relation to that technological obsolescence.

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