The Evolution of Small Change*

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ABSTRACT

Western Europe was plagued with currency shortages from the 14th to the 19th century, at which time a 'standard formula' had been devised to cure the problem. We document the evolution of monetary theory, policy experiments and minting technology over the course of six hundred years. In a companion paper, we use a cash-in-advance model of commodity money to provide an analytical framework for the problem of small change.

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Introduction

This paper traces the process through which western monetary authorities learned how to supply small change. Western Europeans long struggled to sustain a proper mix of large and small denomination coins, and to escape from the prescription that coins of *all* denominations should be full-bodied.

The monetary system begun by Charlemagne about A.D. 800 had only one coin, the penny. At the end of the twelfth century, various states began also to create larger denomination coins. From the thirteenth to the nineteenth century, there were recurrent 'shortages' of the smaller coins. Cipolla (1956, 31) states that "Mediterranean Europe failed to discover a good and automatic device to control the quantity of petty coins to be left in circulation," a failure which extended across all Europe.

By the middle of the nineteenth century, the mechanics of a sound system were well understood, thoroughly accepted,[1] and widely implemented. According to Cipolla (1956, 27):

> Every elementary textbook of economics gives the standard formula for maintaining a sound system of fractional money: to issue on government account small coins having a commodity value lower than their monetary value; to limit the quantity of these small coins in circulation; to provide convertibility with unit money. . . . Simple as this formula may seem, it took centuries to work it out. In England it was not applied until 1816, and in the United States it was not accepted before 1853.

Before the triumph of the 'standard formula', fractional coins were more or less full bodied, and contained valuable metal roughly in proportion to their nominal values, contradicting one element of the standard formula.[2] Supplies

[1] For example, see John Stuart Mill (1857, chapter X, Section 2).

[2] Going back further in time, Burns (1927, Ch. 12) finds evidence of token coinage for small denominations in Greek and Roman times. We start our study with the Middle Ages.

were determined by private citizens who decided if and when to use metal to purchase new coins from the mint at prices set by the government, contradicting another element of the standard formula. That system produced chronic shortages of small coins, but also occasional gluts. The process by which a cure was invented for these problems provides a fascinating window on the growth of monetary theories and institutions, and a wonderful case study of 'social learning'. Commentators reasoned about the problem and tried to make sense of their observations, building up monetary theory in the process. Governments ran diverse 'experiments', more or less informed by the commentators' advice. Technical innovations in metal working altered the relative costs of legal and illegal suppliers of small change, and affected feasible policies. It took centuries to leave behind the idea that small coins should be full bodied.[3] Governments long experimented with token coinage before they discovered, or accepted, that as in Cipolla's standard formula small change should be tokens backed by a government standing ready to exchange it for full bodied large denomination coins or currency.

The evolution of monetary doctrines about small change was an integral piece of the process by which a managed fiat currency system came to be understood and implemented. Apart from the unessential detail of the substance on which a 'promise' is printed, a token coin is like a government or privately supplied paper bank note. After a long process of theorizing and experimenting, most governments eventually monopolized the issuing of bank notes and token coins. The process of thinking about small change and the feasibility of a system of token small coins refined the quantity theory.

The Sargent-Velde (1997) model identifies a set of particular circumstances that made the 'pre-standard formula' regime likely to produce shortages of small coins, and describes 'cures' for those shortages in the form of debasements and reinforcements of the coinage. The supply side of the model deter-

[3] "Monetary policy would have faced fewer difficulties if the commodity money concept of money had commanded less respect. Its persistence as an ideal obstructed and delayed the development of a workable system of redeemable token money" (Usher, 1943, 196).

mines a set of intervals, one for each denomination of coin, within which the price level must reside if both coins are to circulate. Were the price level to hit the lower bound for a particular coin, that coin would be minted; were it to hit the upper bound, the coin would be melted. Thus, the existence and supply of any particular coin depends on the position of the price level with respect to that coin's interval. The sizes of these intervals depend on the production costs and the seigniorage taxes (or subsidies) for each coin. The model asserts that only if costs and seigniorage rates are properly aligned can all coins be jointly supplied, and episodes of shortages be ruled out. Further, the technological fact that production costs are proportionately *larger* for smaller coins makes smaller coins the ones that are vulnerable to episodes of shortage. In the model, the government sets the limits of the intervals (the 'mint prices' and the 'mint equivalents') by choosing the weight of each coin and the coin-specific seigniorage and brassage rates. In making these choices, the government is constrained by its production costs and by those of its competitors (counterfeiters and foreign mints). Technological developments in the minting process can provide the government with a cost advantage and give it more freedom to adjust the intervals properly, at least for a while.

The demand side of the model amplifies Lucas's (1981) model to incorporate two cash-in-advance constraints, one like Lucas's that constrains all consumption purchases, and a new one that constrains small purchases. These constraints capture how small denomination coins can be used to purchase expensive items, but large denomination coins cannot be used to buy cheap items: they model a demand for 'change'. The addition of the cash-in-advance constraint for small change (denoted as the 'penny-in-advance or p. i. a. constraint') adds an occasionally binding constraint and an associated Lagrange multiplier that plays a decisive role in characterizing 'shortages' of small change. When the p. i. a. constraint is not binding, the model exhibits a version of penny-versus-dollar exchange rate indeterminacy, a feature of many models with inconvertible currencies. So long as pennies and dollars bear the same rates of return, holders of currency are indifferent to the ratio in which they hold pennies and dollars.

'Shortages' of pennies are manifested in a binding p. i. a. constraint, and the emergence of the condition that the rate of return on dollars dominate that on pennies. This rate of return dominance is the market signal that causes money holders to conserve on pennies. Exchange rate indeterminacy breaks during small change shortages. The model makes contact with the 'quantity theory of money' in various ways. The ranges between the melting and minting points for large and small denomination coins creates a price level band within which the ordinary quantity theory operates, cast in terms of the total quantity of money. This operates during periods in which coins of both denominations are circulating and neither is being melted or minted. During periods in which the p. i. a. binds but in which neither coin is melted or minted and both circulate, the quantity theory breaks in two, with one holding for 'dollars', another for 'pennies'. Another version of the quantity theory holds in a regime in which the parameters of supply have been set to cause all large denominations to disappear because they have been driven out by token small coins.

We use the model to understand how shortages can emerge, and how they might be corrected within the rules of the Medieval monetary mechanism. For example, under the Medieval mechanism, by making the p. i. a. constraint binding, the price signals induced by 'shortages' of small change perversely hasten the day when small coins will eventually be melted unless there are adjustments in the parameters governing the melting point for small coins. This feature of the model inspires an interpretation of debasements of small coins as a cure for shortages of small change within the mechanism.

The model also formalizes the workings of the various corrective elements of Cipolla's 'standard formula', including the possible roles of a government monopoly rather than privately chosen quantities of small denomination coins; of convertibility; of limited legal tender for smaller coins (which modifies the cash-in-advance constraints) and how they embody the 'quantity theory'.

With the model in mind, we turn to the historical record, and trace the evolution of small change as a process involving technology, theory and pol-

icy. We begin by describing the Medieval mechanism for providing coins, and documenting recurrent shortages and occasional gluts of small coins throughout medieval and early modern Europe. We describe the technology for producing coins, and how it changed from 1200 to 1816, occasionally changing the cost parameters of the government. We describe the development of ideas about small change: churchmen thinking about equitable seigniorage rates and policies toward debasement, secular lawyers coping with the coin denominations in terms of which debts were contracted and expected to be repaid (legal tender); how coins were to be valued, by weight or by tale. We describe how technical developments in metal working prompted the government of Spain to embark on an experiment that initially offered efficiency gains promised by a well managed fiat currency system, based on token copper coins; and how failure to limit quantities ultimately created unprecedented inflation. We cite commentators who responded to these observations with a sharp defense of limited legal tender provisions for small coins, based on a quantity theory of money. We describe how, within decades of the Castilian experiment, Sir Henry Slingsby (1670) stated the 'standard formula', and how it took another century and a half before his recommendation was implemented. We close by endorsing Angela Redish's account of how technological changes in metal working affected when the standard formula was to be first implemented in Britain.

Small Change in the Middle Ages

Billon Coinage

In Medieval times, small change was either pure silver or *billon*, a mixture of silver and copper, whose silver content was either proportional to or lower than its face value.

In England, the small change was silver. The royal mint never minted below sterling (92.5%) until 1672.[4] The smallest coins (pennies, halfpence and farthings) were sterling silver, and therefore extremely small. Pennies were often broken up to create halfpence.

In other countries, silver was mixed with copper to create larger, more convenient coins, but the silver content of the lower denominations was proportional to their face value, as compared to larger coins. This was the case in France until the mid-16th century. When debasements occurred in medieval times, the entire denomination structure was debased simultaneously. During periods of intense debasement (1340–60, 1417–29) no small coins were minted. Originally, small coins were under the same free minting regime as larger coins, but by the 1480s, small denominations were only minted on government orders, and at times and in specific areas, prohibitions were even placed on minting.

In addition to silver and full-bodied billon coins, a third form was coins that were "light" relative to higher denominations, usually by no more than 10 or 20%. Examples are found in Spain, the Low Countries, and Italy. For example, when the quattrino of 4d was first minted in Florence in 1332, it was 17% lighter than the guelfo of 30d. In the course of debasements, the relative contents could change. In 14th and 15th century Florence, the three silver coins were the grosso, the quattrino and the picciolo. In 1366, the picciolo only was

[4] With the exception of the Great Debasement of 1540 to 1550.

debased; in 1371, the quattrino was debased; in 1385 and in 1461, the grosso was debased; in 1472 the quattrino and the picciolo were debased.[5]

How 'small' was small change? Munro (1988) provides detailed information on the purchasing power of the Flemish penny, and concludes that "small silver and petty coins played a far greater role in medieval society than they do in today's economy. For most people, such coins were then certainly the principal means, for many the only means, of transacting retail trade, in buying and selling daily necessities."

Table 1 compares the denomination structure with the daily wage of unskilled labor at various dates in Western Europe. Typically, the daily wage represented 1 to 3 silver coins, and thus daily necessities required smaller coins. Another way to appreciate the size of small change is to look at what the smallest silver coin could purchase. In Florence, in the second half of the 14th century, the smallest silver coin was the *guelfo* of 5s: it could purchase 5 liters of the cheapest wine, 1 kg of mutton, 20 eggs, 1 kg of olive oil; or pay a month's rent for an unmarried manual laborer (La Roncière 1983).

[5] Curiously, from 1461 to 1471 the quattrino was actually the heaviest coin, and the grosso (worth 80d) was 14% lighter. See Bernocchi (1974, 3:302–8) and Cipolla (1990, 191–209) for details.

Place and time	*Daily wage*	*Existing denominations*
Paris, 1402	30d	1/2, 1, 2, 5, 10, *270*
Paris, 1460	35d	1, 3, 10, 30, *330*
Florence, 1347	30d	1, 4, 32, 48, *744*
Flanders, 1389	48d	1/2, 1, 24, *528*
Low Countries, 1433	60d	1/2, 1, 3, 6, 12, 24, *288, 576*
England, 1349	2.2d	1/4, 1/2, 1, *20, 40, 80*
England, 1467	5d	1/4, 1/2, 1, 2, 4, *30, 60, 120*
Castile, 1471	25mr	1/2, 2, 4, 31, *420*

Table 1: Daily wage for unskilled labor and denomination structure of coinage in late Medieval Europe. Denominations of billon coins are in smaller font, those of silver coins in normal font, those of gold coins in italics. Units are the local pence (deniers, denari; deniers parisis for Flanders; maravedis for Castile).

Sources: France: Baulant (1971). Florence: La Roncière (1983, 326). Flanders, Low Countries: Verlinden (2:95, 4:325). England: Postan (1973, 199). Castile: MacKay (1981, 146).

The Technology

The Hammer and The Pile

Most mints were contracted out to private entrepreneurs who were usually allowed different charges for different denominations.[6]

After melting and refining the metal, the technology for making coins involved three main steps: preparing sheets of metal, cutting the sheets into blanks, and striking blanks. From Greek and Roman times to the Renaissance, the technology employed in each step remained unchanged.[7] The metal, once brought to the desired standard, was hammered into a sheet, and then cut into

[6] See Mayhew (1992, 99–103, 114–21, 140, 148, 152–8, 166–71) for the English mints, Blanchet and Dieudonné (1916) for the French mints. Spufford (1988) confirms that similar arrangements prevailed in the Low Countries and elsewhere. The cities of Florence and Venice managed their mints directly; but, as elsewhere, the mint merely posted prices and let the private sector choose quantities.

[7] This account is based on Blanchet and Dieudonné (1916), Wendel (1960), Cooper (1981).

squares with shears. Each square was adjusted in weight and then beaten into a round shape. The resulting blanks were blanched to remove tarnish, and then struck.

The striking process itself was simple: the lower die or pile, whose other end was shaped like a spike, was driven into a wooden block. A worker put the block between his legs, placed a blank on the pile, placed the upper die or trussel on top of the blank and struck the top of the trussel several times with a hammer. The dies were made locally by the mint's engraver on a pattern provided by the central government. The engraver prepared a collection of punches, each bearing in relief one of the elements of the coin's design. He then used the punches to engrave the dies with the design, replacing them as they wore out.

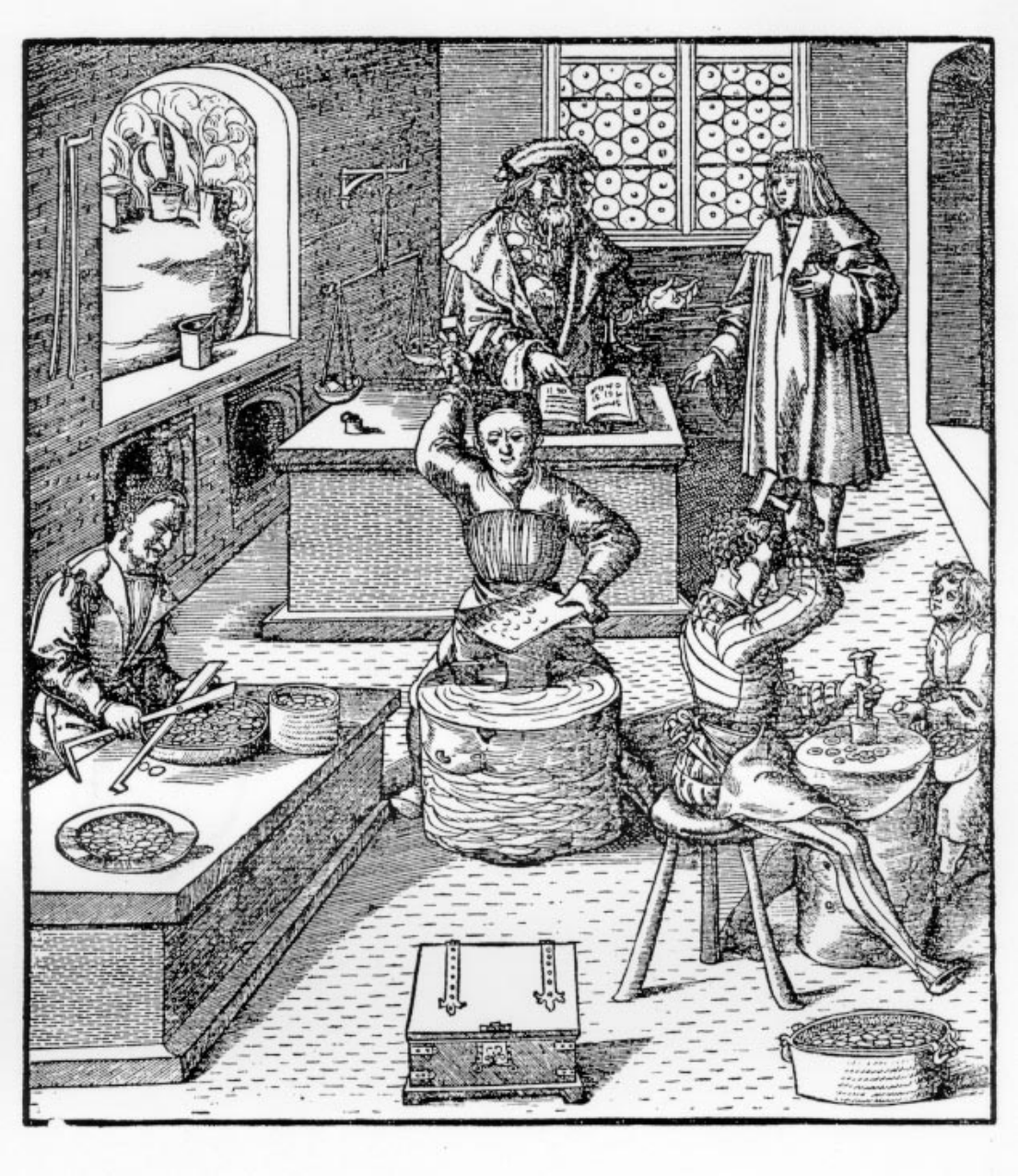

Figure 1: A late medieval mint (engraving by Leonard Beck to illustrate *der Weißkönig*, 1516).

The technology required specialized labor: hammering, cutting, blanching and striking were each performed by different laborers, usually members of a privileged (and hereditary) corporation. The tools were simple, the plant was

of limited size (furnaces were the largest piece of equipment), and minting could be carried out in a decentralized fashion. But this technology had serious drawbacks. Since dies were produced locally, with common goldsmith's tools, there was considerable variation in the style and quality of the imprints on the coins, and an approximate imitation could pass as genuine. The process produced imperfect coins of varying size and weight, with a poorly centered imprint, making it difficult to spot an altered coin. The coins were thus subject to falsification,[8] and to clipping.

Production Costs and Seigniorage

Per unit of value, the production process made small coins more expensive to produce than larger ones, since the same effort was required to strike a coin of any size, and not much less to prepare smaller blanks than larger blanks. Table 2 presents data on production costs from a variety of Western European countries in the Middle Ages.[9] Who bore those costs varied by country.

In England, after 1351, a flat rate was allowed the mint-master for all coins of the same metal, leaving strong incentives to make only the largest coins. Occasionally, the proportions of the various coins were specified in the contract, but the king could not force a competitive bidder to assume such costs. In 1461-2 the choice of the mix of denominations in production was left to the discretion of the comptroller, a government official, who should consult "the desire, ease, and content of the People." Production remained strongly biased toward large coins until a complete scale of differential payments across denominations was adopted in 1770.[10]

[8] There are two kinds of counterfeit: coins that are not full-bodied, for instance plated or hollowed-out or made of a sub-legal alloy; and coins that are essentially identical to legal coins, but not produced by an official mint. In the second case, the only loss is incurred by the sovereign who loses seigniorage; but measures designed to prevent the first kind of counterfeit were bound to help prevent the second kind.

[9] Sprenger (1991, 83) gives similar figures for Germany, 2% for Florins, 7% for Schillings and 15% for Hellers.

[10] Craig (1953, 75), Mayhew (1992a, 168).

	name of coin	*legal value*	*silver/gold content (mg)*	*brassage (%)*
Florence, 1347	picciolo	1d	52	15.65
	quattrino	4d	217	6.22
	grosso	32d	1960	1.20
	fiorino	744d	3537	0.14
England, 1349	farthing	0.25d	283	3.64
	halfpence	0.5d	570	2.96
	penny	1.0d	1178	1.94
	noble	80.0d	8188	0.42
Flanders, 1389	double mite	0.08d	53	43.71
	gros	1d	1018	9.73
	noble	72d	7649	1.58
France, 1402	denier	1d	145	10.67
	blanc	10d	1448	6.46
	écu	270d	3948	0.72
Low Countries, 1433	double mite	0.08d	45	36.34
	gros	1d	814	4.51
	philippus	48d	3598	0.94
Milan, 1447	denaro	1d	37	20.50
	sesino	6d	272	8.56
	grosso	24d	1175	2.25
France, 1460	denier	1d	109	12.50
	blanc	10d	1086	4.94
	gros	30d	3258	2.32
	écu	300d	3321	0.56
England, 1467	penny	1d	707	3.11
	groat	4d	2828	3.11
	ryal	120d	7643	0.55
Castile, 1471	blanca	0.5mr	39	24.39
	real	31.0mr	3195	1.49
	enrique	420.0mr	4553	0.50

Table 2: Production costs (brassage) of coinage in late Medieval Europe. Gold coins are in italics. Legal values are in local pence (deniers, denari) or maravedis (in Spain).

Sources: Milan: Cipolla (1990, 111–23). Florence: Bernocchi (3, 33–44). Castile: Perez Garcia (1990, 115). France: Saulcy (1879–92, 2:117, 3:226). England: Challis (1992, 703, 713). Low Countries: Munro (1972, 202–5) and Munro (1988, Table 5).

In Florence, whose mint was run directly by the city, the opposite tack was always taken, namely, charging private parties for costs. In 1347 (the period for which the figures in Table 2 apply), the seigniorage rate was 0.6% for the gold fiorino, 4.6% for the grosso, 6.6% for the quattrino and 17.8% for the picciolo (Bernocchi 1974, 3:38–40).

In France and the Netherlands, the mint-master was allowed to deduct different production costs from gross seigniorage.[11] This arrangement in effect paid for the different costs out of the king's seigniorage. Furthermore, the output mix between gold and silver was often part of the contract, but only the aggregate value actually mattered, and quantities of small currency were never specified, leaving their determination to public demand and the mint-master's incentives. The mint-master's only obligation was to provide a minimal amount of net seigniorage during his lease. Since he could meet his obligation with any mix of coins, he preferred to mint larger denomination silver coins, unless ordered to do otherwise.

Recurring Coin Shortages

Monetary historians (Spufford 1988, 361–2, Carothers 1930, Van der Wee 1969, Munro 1988, Cipolla 1956), testify that there were commonly coin shortages, specifically shortages of small coins (petty coinage, black money) commonly occurred in Medieval and Early Modern Europe.

In the 15th century in the Burgundian Netherlands, "continual demand for small change, the lack of which was frequent topic of popular complaint. . . . There was a considerable lack of official small change from time to time, accentuated perhaps by hoarding of even the smallest denominations. The government, perhaps on the insistence of the estates, attempted to remedy this deficiency

[11] The mint price for low-grade silver was usually lower, by as much as 10%; but the mint price does not seem to have depended on the coins in which it was paid.

by writing into the monetary ordinances stipulated proportions of bullion to be used in the minting of different denominations. Comparison between the stipulated proportions and the actual quantities of bullion used indicates that such stipulations were completely disregarded by the mintmasters" (Spufford 1970, 51, 44).

In France, from 1373 to 1397, royal ordinances repeatedly cite lack of small change, and orders were regularly issued to various mints specifying quantities to be minted. Such orders appeared again in 1458 and 1461, when small change was minted with express instructions to subsidize its cost out of other seigniorage revenue, and recurrently again after 1488 (1488 to 1493, 1498 to 1501, 1508 to 1513, 1520 to 1522, etc). There were complaints of lack of small change in 1544; curiously, at the same time the government forbade mints to make small change without prior authorization, and prohibitions on minting small change were occasionally issued (e.g., in 1545).[12]

In Spain, which consisted of separate kingdoms until the late 15th century, there were often shortages of small coins. In Aragon, complaints were voiced from the 1370s. In 1497, to remedy "the great dearth of fractional money in the kingdom," a commission was formed and as a result new billon pennies were minted that were 21% lighter than silver coins (Hamilton 1936, 87–90). The quantity minted was limited to 20% of the total silver coinage, and a legal tender limit of 5d was imposed. In Navarre, a "great scarcity" of fractional money was noted in 1380 and prompted an issue of billon pennies 18% light. Similar complaints arose in 1430 and in 1481. In 1487 the kingdom was said to "suffer great injury on account of the complete lack of fractional money" (Hamilton 1936, 126–34). Valencia and Barcelona seemed by and large to be free of such problems. In the 1530s, during a scarcity of vellon coinage in Castile, *tarjas* (coins from nearby Navarre) circulated at $\frac{1}{3}$ above their intrinsic content. The Cortes of Castile asked the king for issues of vellon in 1518, 1528, 1542, 1551, 1558, 1559, 1583–85 (Hamilton 1934), and there was a small premium on vellon with respect to silver in the late 16th c. (Domínguez Ortiz 1960, 238).

[12] Saulcy (1879–92), passim.

In medieval England, counters struck in Nürnberg became current around 1328, and were prohibited in 1335. Private tokens are first mentioned in 1404 in a petition from the Commons to the king (Boyne 1889, xx). In the late 14th and early 15th c., pressure was put on the mint to make more small coins. It was forced to put ⅓ of all silver received into lesser coins. Pence were cut in half for change in 1393, 1402 and as late as 1446, as observed in a complaint of the Commons on the lack of halfpence and farthings: "traveling men were often forced to break a penny in two for change". At the same time, private lead tokens circulated as farthings. The ships of Venice brought to London immense quantities of 'galley' coins which were worth about a farthing, yet passed as half-pence; they were prohibited by name in 1399, 1409, 1411, 1423, and as late as 1509 (Craig, 81–82, 87). Token coinage at the end of Henry VII (early 16th c.) is mentioned in Ruding, vol. 2 p. 69.

In the late 16th century, few if any coins were struck below sixpence. In 1582, resort to private tokens was rampant (Craig, 128). Elizabeth I authorized Bristol to issue lead tokens current within 10 miles of the city. Scarcity of small change led to private issues of substitutes in lead, brass, copper, or paper. In London alone it was estimated that 3,000 trades people issued tokens in the amount of 5 each.

Monetary Theory

During the Middle Ages, three groups wrote about monetary matters: theologians, legists specialized in Roman law, and canonists specialized in canon law.[13] Theologians worked from a combination of Scriptures and Aristotelian writings. They studied money partly because its existence and ultimate purpose had to be accounted for, partly because Aristotle himself had discussed money in his writings. Indeed, Aristotle's brief discussions of money (in *Politics* 1.6 and *Ethics* 5.8) provided the basis for their abstract conception of money. The two passages are somewhat at odds with each other: in *Politics*, Aristotle clearly discusses money's role as a medium of exchange, and describes it as a commodity chosen because of its suitable characteristics to obviate the inconveniences of barter. But in *Ethics*, he discusses money as a standard of measure, and derives the word for money ($\nu\acute{o}\mu\iota\sigma\mu\alpha$) from the word for law ($\nu\acute{o}\mu o\varsigma$), thus making "money a convention, and it is in our power to change it or make it valueless." The passage from *Politics*, however, provided inspiration for several passages of Roman Law,[14] which in turn shaped legal thinking throughout the Middle Ages, and the implications of the passage from *Ethics* were by and large ignored.

Among theologians, the political economy of money attracted attention. In particular, nominalist writers such as Jean Buridan in the 14th century and Nicole Oresme (c. 1320–1382) provided the most interesting views. Oresme states that money as an institution belongs to the community, for whose welfare it was created, and that its management must be subordinated to the common welfare. He sees monetary manipulations as a form of taxation, for which the assent of the taxpayers is required.

Legists and canonists both worked from an initial body of texts (Roman law and the Church's regulations, respectively), providing commentary and glosses. Both traditions touched upon monetary questions, from the point of view of contracts and legality for Legists, morality and justice for Canonists.

[13] On Medieval monetary theory, see Velde (1997) and the references listed there.

[14] In particular a section of Justinian's *Digest*, written by the 3d c. Roman jurist Paulus, which contains the earliest statement of the "double coincidence of wants" problem.

The Evolution of Doctrine: from one coin to multiple denominations

At the time of the Carolingian reform, the penny, which was the only coin minted, contained about 1.7g of fine silver. Over the following period to 1160, the right to coin money was appropriated by feudal lords and cities, as part of the disintegration of central authority. Each fief or city had its own penny, and these coins were minted with progressively lower amounts of silver. By 1160, European pennies contained anywhere between England's 1.3g to Venice's 0.05g of fine silver, with fineness ranging from England's sterling (92.5%) to Barcelona's 20% (Spufford 1988, 102–3). Yet, everywhere in Europe the penny was the only existing coin; large quantities of pennies were counted in dozens (the shilling) and score dozens (the pound).

Such depreciation rates raised questions when it came to debt reimbursements. If 100 pennies had been borrowed, should 100 current pennies be repaid? Where money existed simply in the form of the penny, with no other denomination, the answer seemed fairly straightforward, and standard Roman law was applied to money as if it were a commodity. The earliest known commentary on the case is by Pillius, around 1180, quoting his master Placentius, in the case of a 5-year loan in pennies of Lucca. The Roman law he applied (Dig. 12.1.3) states that "the debtor is not allowed to return a worse object of the same nature, such as new wine for old wine" and that the debt must be repaid with something "of the same kind (*genus*) and the same quality (*bonitas*) as that which was given." The Roman law was clearly concerned with commodities, but Pillius and subsequent glossarists such as Azo (d. 1220) and Accursius (d. 1260) applied it as such to money. Azo formulated a famous brocard (an elementary principle or maxim): "The same money or measure is owed that existed at the time of the contract."

In 1201 Venice had exacted a vast amount of silver from the leaders of the Fourth Crusade to ferry them to the Holy Land, and minting them in pennies would have been a huge task. It was decided to start minting a new, larger coin, called the grosso, of much higher fineness. The growing needs of the expanding

economy ensured that, within thirty years, all major cities of Northern Italy had followed suit and issued silver coins of about 2g, which were not designed to replace pennies but circulate concurrently. By the end of the 13th century, every area of Western Europe (except England) had large denomination silver coins circulating alongside the traditional pennies. Since the penny was the original money, the larger coin's values were expressed in pennies. When the grossi were first issued, they were given silver contents which made them into exact multiples of the existing penny. Thus, the Venetian grosso was probably issued so as to be worth 24 pennies, or 2 shillings. As Venice soon found out, it was not easy to maintain a fixed parity between the two coins, because the penny continued to depreciate; by 1282, the grosso was worth 32p.

Since the words 'pound' and 'shilling' meant simply certain numbers of coins, it became customary in some places to speak of 'pounds of such coin' consisting in 240 such coins.[15] Often, governments tried to establish some official rate of a coin in terms of pennies, say N pennies to the coin; but, as the market valuation of the coin changed, accounts were kept in 'pounds' containing $240/N$ coins.[16] Thus, the expression "one pound" could represent different amounts of silver or gold, not only as a function of the date, but also of the type of coin used.

The question of which unit was meant by a 'pound' could, in most cases, be resolved by an appeal to local custom and likelihood: for example, in Venice the *lira di grosso* was 32 times the *lira di piccioli*, and in most cases there

[15] In Venice, the penny or *piccolo* was counted in *lira di piccioli* containing 240 piccioli. The *grosso* was counted initially in *lira di grosso* containing 240 grossi; thus the ratio of one lira to the other was the relative price of the grosso in piccioli (26, 28 or 32). The gold ducat was introduced in 1284 and rated at 18 grossi, and in 1328 at 24 grossi. At that last rate, 1 lira di grossi equaled 10 ducats, and imaginary subdivisions of the ducats were created: the *grosso a oro*, representing 1/24 of a ducat. Later, when the gold/silver ratio changed further, the grosso a oro remained fixed, and a new unit, the *lira di grossi a oro* representing 10 gold ducats was created (Papadopoli 1:380–1).

[16] This was the accounting system prevalent in Florence. As in Venice, gold-based units also developed. In 1252, Florence issued the gold florin at a valuation of 240 piccioli, or one *lira di piccioli*. Over time, a *lira a oro* permanently equal to 1 florin was developed, divided in imaginary fractions of the florin: 20 *solidi a oro* or 240 *denari a oro*. For a while, the florin happened to rate at 29 silver solidi, and another system of fractions of the gold coin developed, the *lira affiorino* (and its subdivisions) consisting in 20/29 florin. The system survived even as the gold florin went on to rate for more than 29 actual silver solidi.

would be little doubt over which was the applicable unit. This line was adopted by jurists, who were usually deferential with respect to local custom. But the existence of exchange rates between coins of various sizes led jurists to conceive that the *bonitas* of a coin is more complex than that of a commodity. By the mid-13th century, the legist Odofredo Denari (d. 1265) had introduced the concept of *bonitas penes usum*, or value with respect to the use. He argued that the 'quality' demanded in Roman law might not be determined exclusively by intrinsic characteristics of the object, at least for some objects, like money, and argued for consideration of the purchasing power of the coin. Jacopo de Arena (d. ca. 1300) coined the terms *bonitas intrinseca* or intrinsic 'quality' of the coin in terms of its pure metal content, and its *bonitas extrinseca*, which is understood to mean its valuation in terms of other coins (the value of a grosso in terms of pennies), or its purchasing power.

Jurists remained divided over the extent to which purchasing power needed to be taken into account in the repayment of debts. One reason was probably the difficulty of measuring a coin's purchasing power. Odofredo's text, as presented by Cino da Pistoia, clearly defines purchasing power. But later commentators, when quoting Odofredo and Arena, seem to take *bonitas extrinseca* to be the market valuation of a coin in terms of pennies, which was more readily observable. Domenico de San Gemignano, writing ca. 1430, makes a full argument for consideration of purchasing power in the case of a rent owed for the purchase of land. Changes in the market value of the proceeds of the land should be taken into consideration in deciding whether to adjust the nominal value of the debt.[17] Other jurists, such as the Neapolitan Andrea d'Isernia, rejected the consideration of extrinsic value: "If I lend you a measure of wheat in May when it is expensive and is worth perhaps 3 tarini, and I reclaim it in July after the harvest when it is worth perhaps 1 tarino, it is enough to return the measure of the same wheat in kind, even though it is worth less; likewise if

[17] Curiously, this reasoning leads San Gemignano to advocate no adjustment in the debt, even though the coinage had depreciated by 25%, although his argument that nominal wheat prices had remained constant in that period is not implausible. See Stampe (1928).

it is worth more, for example if I lent it in July and demanded it in the following May ... the same reasoning applies for money as it does for wheat and wine."

Seigniorage rates

In the late 12th century, another theoretical development took place. In 1196, Pedro I succeeded his father as king of Aragon and swore to maintain the currency as it was (an oath required of the kings upon their accession). He later discovered that the currency had been debased soon before his father's death, and asked the pope to be relieved of his oath in 1199. The pope's decree was included in the body of Church law[18] in the chapter on oaths, but became the occasion for canonists' musings on monetary doctrine. Because the context was not contract law, but rather a sovereign's monetary policy, their attention was partly drawn to new questions. The canonists observed that, in practice, sovereigns were able to levy positive seigniorage. That is, the value at which coins were issued was higher than the intrinsic content. Moreover, the papal decree seemed to declare fraud for a coin whose intrinsic content was less than some expected norm.

The first canonist to comment on this decree was Innocent IV (1195–1254). He attributed the existence of positive seigniorage to the prince's right to issue currency, and to the fact that the prince's mark gave the coin general acceptance, thus adding value. But how much seigniorage was allowable? Innocent IV answered the decisively: seigniorage net of production costs should be zero. The only exception he allowed was in case of emergency, and only for coins circulating domestically, and with the expressed consent of the subjects. Anything else would be fraud. Canonists adhered to this position until the 16th century.

In this respect, they differed sharply from legists. The glossarists of Roman law (Azo and Accursius in the 13th c.) had interpreted the texts they

[18] X 2.24.18. All Roman law and canon law citations will follow the conventions described in Brundage (1995); they have been converted from the medieval method of citation by incipit, using Ochoa and Diez (1965).

knew, in particular the account by the Roman jurist Paulus (d. 235 AD) of the origins of money, in a strict commodity-money view, and saw money as deriving its value from its content, the stamp being a mere convenience. They thus came to insist that money should be worth as much in coin as in bullion, and that the expenses of coining should be borne by the state. This view, expressed most notably by Bartolo da Sassoferrato (see infra), remained that of the legists down to the 16th century as well, even if they acknowledged that it was not observed in practice.

Debasements and Nominal Value of Debts

This recognition that the market value of a coin was higher than its intrinsic value was reinforced by the increasingly common practice of debasement, whereby a king tried to generate seigniorage by producing lighter coins and inducing holders of heavy coins to bring them to the mint for exchange into the new, lighter coins. Thus, variations in the rate (*cursus*) of a coin could come about because of the coin's depreciation, or because of circumstances unrelated to its intrinsic characteristics. Since canonists held strong negative views about currency manipulations and seigniorage above production costs, they condemned debasements in the sphere of public law, and tried to undo its effects in the sphere of private law, namely contracts: this approach was started by Hostiensis (1190–1271), and followed consistently by canonists, who called for total disregard of changes in rates due to currency manipulations by sovereigns driven by "greed".

Philip IV the Fair, king of France, carried out the most spectacular currency manipulations to date between 1290 and 1306, by debasing the penny (*denier Tournois*). By 1302, pennies contained a third as much silver as they used to. In 1306, the king decided to return to the old standard and minted new 'strong' pennies which were officially rated at 3d (in the debased pennies). Then, it was announced that, as of Oct. 1, 1306 the 'strong' penny was to be the standard of account, and all sums expressed in pounds, shillings and pence

should be understood in terms of the strong money. An ordinance of Oct. 4, 1306 prescribed that "All rents shall be paid in good money. Transactions will be settled in the coins current at the date of the transaction. If contracts were written such that payments were to be made over several years, each payment will be made in the coins current in that year. Housing rents will be paid in current money, but if the rent was so high that the tenant would be burdened, it will be paid in the coins current at the time of the rental contract." At Christmas 1306, when landlords in Paris demanded their rent payment in strong money, riots erupted, and the king passed another ordinance allowing for payments of the next three quarters' rents in weak money.

Some jurists were quite uncomfortable with the French king's actions. Cino da Pistoia (1270–1336), who cites the episode, prescribes that debts will be discharged by returning the correct quantity of metal, and not the number of coins. An application of this doctrine appears in the case of a rent of 300 which the pope ordered to be paid annually by the abbey of Cîteaux to the abbey of Clairvaux, in 1302. After the currency reform of 1306, the abbey of Cîteaux argued that he should only have to pay 100 in 'strong' currency. The jurist Oldradus (d. 1335) wrote a *consilium* defending that opinion.

Yet the French jurist Jean Faure (d. 1340), who taught in Montpellier, considered that, debts denominated simply in pounds and shillings could be repaid in current money, whatever it might be: "certainly the king has powers in such matters, and he is competent to set the rate (*cursus*) and value of money." Such a doctrine, termed in the literature 'nominalism,' remained almost unique until the 16th century. Even the French king's courts upheld repayment in the original currency when the obligation arose from a single transaction (Timbal 1:331–91). And Faure himself accepted that the terms of a contract which required payment in specific coin had to be honored. Indeed, although the French king outlawed such clauses in 1330, but the courts nevertheless upheld contracts denominated in specific domestic or even foreign coins, and the prohibition was repealed in 1352 (Timbal 1973).

Another departure from strict adherence to intrinsic content was made by Guillaume Durant (1231–96), who argued that, while intrinsic content was to be used to repay debt contracts, fines, salaries and other sums set by law in units of account had to be interpreted in terms of current money. This opinion was often cited, though not always endorsed (in particular, it was rejected by canonists). French courts appear to have followed Durant: for contracts which required exchange of goods and services against money over time, payment in current money was upheld by courts (Timbal 1973, 331–91).

Fluctuations in the Exchange Rate between Large and Small Coins

The introduction of gold coins such as the florin and the ducat in the 13th century introduced further complexity. The Florentine florin, issued initially at 240d in 1252, had reached 3 or 720d by the early 14th century, and 1000d by the mid-15th century. Such a large price made it possible for small variations to be expressed conveniently, and the florin's daily market value against the penny was observed to fluctuate from day to day, and also to trend up over time. These fluctuations created new problems for jurists, because it was not clear that they were due to any change in intrinsic content of either the florin or the penny (even allowing for depreciation of the penny by wear and tear).

As the synthesis by Panormitanus (1386–1445) shows, canonists remained attached to the precept that variations in intrinsic content should be accounted for, whatever the denomination, and that variations in the rate which did not reflect any change in intrinsic content should be ignored. Thus, day-to-day fluctuations in the market value of the florin were to be ignored; but Panormitanus allows that, if the value seems to have changed permanently, an adjustment should be made.

Bartolo da Sassoferrato (1313–57), a student of Cino da Pistoia and the pre-eminent jurist of the 14th century, provided a new justification for repayment in current coin under certain circumstances. Bartolo did not deviate from the standard view in the case of coins whose intrinsic characteristics have been

altered, and he also endorsed the legal validity of clauses specifying the coin in which repayment must be made.[19] The problem arose when no such clause exists, and sums are denominated in pounds and shillings. Bartolo reads such sums as being quantities of pennies (unless specified otherwise), and argues that pennies are the unit of measure, and the smallest unit: any coin or good can be priced in pennies, but the reverse is not true. Therefore, the value of the penny cannot be said to have changed, and no adjustment is necessary: sums in units of account are repaid in current money. The reasoning then relies on the medieval distinction between incurring a loss, which the debtor must compensate, and missing out on a profit, which is the creditor's problem. That the creditor could have bought other coins with N pennies and obtained more than N pennies today is a lost profit, not an actual loss. This opinion was rejected by some, in particular canonists. St. Antoninus of Florence countered that "just as a florin can be bought with piccioli, so piccioli can be bought with a florin if some necessity requires it."

Bartolo nevertheless endorsed the general principle that the creditor could not be forced to accept repayment in another metal than the one lent if he were to suffer a loss thereby; but if there is equivalence in metal content, the creditor could not object. He also let the local custom override his own prescriptions, when applicable.[20]

The Invention of Fiat Money

Canonists had allowed for limited debasement in cases of emergency. This exception was developed further by a line of jurists, Andrea d'Isernia (1220–1316), Matteo d'Afflitto (1443–1523) (both in Naples) and Gabriel Biel (ca. 1430–1495) in Germany. D'Isernia allows for debasements when the price

[19] Although he held that merely specifying the coin in which the original payment had been made was not sufficient.

[20] In the statutes, legal tender limitations were introduced only slowly, because small coins remained close to full-bodied. There were a few examples in the late Middle Ages, usually in association with the issue of light pennies: for example, new Aragonese pennies were limited to 5d in 1497. In England, in 1445, half-pennies and farthings light by 10% were minted for two years and their legal tender limited to 1/20 of a debt (Craig, 87).

of silver as metal has been changed: for example, when more metal is discovered in mines than before, or more is extracted, or when a passing army spends large amounts of money and raises prices. Depreciation or appreciation of silver can be compensated by making larger or smaller coins. Long-term deterioration of the coinage, by wear and tear or oxidation, is also a legitimate ground for debasement, and the consent of the people is not required because the prince acts for the common good.

But d'Isernia also makes the observation that kings in emergencies often make money from base material such as iron or leather and order it to be accepted as if it were good money, because "the common good is preferred to the private good." D'Isernia finds this acceptable,[21] even without the explicit consent of the people, but on certain conditions. Once the emergency has passed, the king must compensate the holders of the vile money, and accept it in exchange for good money (Isernia points out that the current holders of the money need to be compensated, not the original recipients). Matteo d'Afflitto repeats these prescriptions and strengthens them: failure to redeem the emergency money is a mortal sin: "Alas! How many princes have been damned because of this, and indeed we have seen in past wars many men destroyed because they sold their goods for vile money such as new copper pennies and after the peace was made those pennies were worth nothing."

The emergence of the modern state in 16th century Europe was accompanied by a radical change in thinking about the nature and value of money. As we said earlier, Scholastics distinguished between intrinsic content and market value, but insisted that the two remain identical or nearly so. They also denied kings the right to circulate coins far above their intrinsic content, and to

[21] He does not argue in favor or such methods. But in the late 15th century, Biel notes that "some think that in case a large sum of money must be collected for ransoming a prince or for defense, an alteration in the coinage is the better and more expeditious method. They reason that this is the easier way to collect quickly the required funds without fraud and undue exactions from the subjects. It is, moreover, felt less and for this reason more easily borne without protest and without the danger of a rebellion on the part of the people. It is the most general form of taxation embracing all classes, clergy, laity, nobility, plebeians, rich and poor alike. But whether these reasons are valid or not, I leave to the diligent reader" (Biel 1930, 34–5).

debase the currency without the consent of their subjects. Faced with repeated episodes of debasements, a degree of realism crept into jurists' writings. Thus, Martino Garati (writing in 1438 in Milan) concedes that if a prince has been free to alter the currency without popular consent for as long as anyone remembers, he may rightfully continue to do so; and Grimaudet, writing in 1575, restates the traditional medieval doctrine but adds that, in France, the king's power is absolute and he may do as he please with the currency. Aristotle's passage on money as a convention was adduced as authority.

Besides the question *de jure* was the question *de facto*: could a coin's two values, intrinsic and extrinsic, be substantially different? In the late 15th century, a few writers assert this possibility: Girolamo Butigella (1474–1515), an Italian jurist, wrote that "in a coin no attention should be paid to the material, nor to the intrinsic value, or quality, or weight: but only to the public valuation, so that it would be possible to make a money of lead, or leather, as long as it be publicly approved, and it would then be possible to use it to repay a contractual debt in place of any gold or silver money." The jurist Matteo d'Afflitto (1443–1523) also held the same view, which, although violently rejected by some writers,[22] proved influential in the second half of the 16th century. For example, the French jurist Grimaudet (1585, 18) typifies a new mode of inquiry which relied much more on historical precedent and factual observation than had Scholastics. While he does cite the Canonists' and the legists' standard views on money, he then adds that "the opinion of those who think that the value of money is in the will of the Prince, is the one always put in practice, and from this Princes have drawn great profit above and beyond the value of the content." He then lists examples of coins made of lead or leather in Scandinavia and medieval Germany, examples of necessity money, as when the Emperor Frederic II, besieging Faenza in 1241, paid his troops with leather money which he redeemed into gold after the siege and mentions Chinese "paper-money of square shape with the image

[22] Charles du Moulin (1577, §798), who quotes Butigella, rejects the view as "irrational and ridiculous: indeed, by the same reasoning it would be possible to make a money out of paper imprinted with a design, which is no less ludicrous and ridiculous than a child's game, and not only contradicts the origin and definition of money, but also experience and common sense."

of the king imprinted on one side." He concludes that, "although we see that princes can make in other material than metal, nevertheless the most common habit among men has been to make money in metal," but sees this as a matter of convenience. The material value is "taken into account by the Prince only in the minting" and "subjects have no power to refuse money in trade on the grounds that the imposed value is higher than the value of the content, as we see in the case of billon money where the imposed value is six times higher than the content."

In a similar vein, Budel (1591) cites the case of obsidional monies[23] (lead in Vienna in 1529, tin in Neuss, copper in Maastricht in 1579, paper in Leyden in 1574) and concludes: "I hold it to be indubitable that a Prince in the midst of costly wars, and therefore in great necessity, can order that money be made out of leather, bark, salt, or any material he wants, if he is careful to repair the loss inflicted thereby on the community with good and better money." A few years later, the Spaniard Pedro de Valencia states that "this has been to relieve immediate needs, for that one time, and not so that these who receive them should be regarded as actually having been paid, but that they should serve as credit certificates, in order that the republic or captain that used such a system should, as soon as possible, make final payment in true, legal money" (Grace-Hutchison 1993, 84). The restrictions which they both placed are reminiscent of the allowance which canonists made for high seigniorage rates justified by financial necessity.

Ultimately, one sees a writer such as Jakob Bornitz (1608) define money not based on its intrinsic characteristics, but on its function: returning to Aristotle's narrative of the origin of money, he defines it as "any object of public value measuring (*aequaliter dimetiatur*) goods which are not commensurate (*inaequales*)". He admits that this definition includes both "true money", made of things that best fulfills the monetary function (divisible, stable value, etc), as

[23] The Oxford English Dictionary defines "obsidional" to mean "of or pertaining to a siege", and "obsidional coins" to mean "coins struck in a besieged city to supply the want of current coins."

well as "quasi money", which lacks something of true money, but has received the stamp of public authority. But, while the content is the "material cause," the public stamp is the "efficient cause."

The major practical challenge of medieval jurists had been to define legal tender rules. In this area too, writing in the second half of the 16th century represents a radical departure. The turning point is undoubtedly Charles Du Moulin's *De Usuris*, first published in 1546. He firmly rejects the relevance of intrinsic content in almost all cases of contractual payments. He reinterprets the medieval *bonitas intrinseca* to be the face value, determined by public authority, rather than the market valuation, and adds that "the rate and imposed value of any money is properly speaking its true intrinsic value, inasmuch as it is considered as money, of gold or silver; to consider it as matter is to consider it not as money." The public authority's valuation of coins cannot be questioned, unless it is clearly arbitrary, unstable and driven by profit.[24] Du Moulin's writings were very influential. Considered the best jurist of his time in France, his position on debt repayments is cited with approval by many subsequent writers. His writings also reflect a shift in jurisprudence. While medieval courts did not enforce repayments at face value and protected clauses which required payment in specific coins,[25] by the 1530s Du Moulin himself, as solicitor, was successfully arguing before the Paris Parlement that such clauses are void, and that only the nominal value of a debt matters.[26] This altered the very concept of denomination. As pennies themselves became secondary coins, used only for very small transactions, and produced infrequently by the mints, the unit of account ceased to mean "240 pennies", but progressively became an abstract measurement unit, whose equivalent into coins was not precisely defined at any time.

The sixteenth century therefore saw a shift toward the concept that intrinsic content was not the main determinant of the value of money. This shift

[24] Du Moulin's 'nominalism' makes his violent rejection of Butigella's fiat money rather puzzling.

[25] See Timbal (1973).

[26] Thireau (1980).

was clearly due to an accumulation of evidence pointing to the possibility, and was comforted in legal theory by the rising model of the Prince as absolute ruler. The resulting theory, dubbed "chartalism" or the "state theory of money" in the 19th century,[27] emphasized legal restrictions or conventions over intrinsic content, and admitted the theoretical possibility of intrinsically worthless money. It was in this context that certain technological innovations occurred.

Theory ahead of Technology

For brass I will bring gold, and for iron I will bring silver

Isaiah 60:17

By the end of the Middle ages, theorists accepted that a coin's intrinsic value could diverge from its market value. Whether divergence could be sustained other than by legal restrictions or particular circumstances is not entertained in the writings we know. But someone must have hit upon an early formulation of Cipolla's standard formula, specifically in Catalonia around 1481.

Catalonia, ruled by the king of Aragon, suffered from small change shortages like many other countries. The town of Gerona had some experience with token coinage. In 1462 and 1463, the town was besieged: its commander issued obsidional money, which the town continued to issue after the siege, but which depreciated. Still suffering from a scarcity of small change, the city asked permission from the king to issue small change, and the king granted it. In 1481, he allowed Gerona to issue coins of whatever metal they wished, but no more than 200 llivres, and on condition that "the city be known to pledge, and effectively pledge to receive said small money from those who might hold it, and to convert it and return for it good money of gold or silver, whenever and however much they be asked." The king required the city to appoint an individual to carry out the exchange.[28]

[27] See Knapp.
[28] Botet i Sisó (1908–11, 2:326–37, 3:11–40, 3:480), cited in Usher (1943, 232).

Initially, Gerona withdrew the remaining siege money and restamped it. The collection fell short of the 200 llivres, and it was decided to mint new coins copper alloyed with 6.25% silver. The resulting coinage contained 25% of the silver in an equal face value of croats, the main silver coin. A total of 1,300 llivres of such coins was minted between 1482 and 1484. The coins depreciated, in part because of counterfeits, and in 1489 the town was authorized to announce a recall for 15 days, after which it was not obliged to convert them anymore. The coins found to be genuine were countermarked and issued again; the next year, another series was issued, of pure copper.

In 1494, an interesting episode occurred: as part of a kingdom-wide monetary reform, the king had placed a legal tender limit of 6d for small change. As a result, the coinage of Gerona was less demanded and many coins were turned in for exchange, at great cost for the city. Gerona applied for relief from the king and was authorized to maintain the currency at its original legal tender value for three months, presumably without convertibility. A restamping operation was also carried out. More operations of restamping and new issue were carried out in 1510 and in 1515: the latter occasioned difficulties because the city found more than half of the coins to be counterfeits. These new issues were convertible, and the issues from 1515 contained 4% silver. In 1535, the large number of counterfeits gave rise to a rumor that the city would suspend convertibility, and another restamping operation was carried out to remove counterfeits. The last authorization for Gerona was in 1575.

Gerona's innovation was quickly imitated by several other Catalonian cities: about a dozen are known to have issued convertible coinage in pure copper or billon. Sometimes the city was required to commit in writing to the convertibility into royal coins of gold or silver current throughout Catalonia. The profits were presumably retained by the city, but often it was specified that they must be used for the upkeep of the city's military installations. The coins were often given legal tender value in a very limited range around the city. Indeed, the capital, Barcelona, which was the seat of the official mint, disapproved of

these local currencies, maintaining that only it had the privilege to mint royal coins, and prohibited the local issues on its own territory.

The problem of counterfeiting was prevalent, and restamping operations were carried out as in Gerona. In 1532 the city of Vic tried to forestall depreciation by agreeing to buy back counterfeits, but this only increased counterfeiting and it soon had to resort to a restamping. The last issue to be specifically convertible was in 1576 in Puigcerdà, and it was legal tender throughout the Rosselló and Cerdanya region (in spite of the protests from the city of Perpinyà).

This first attempt at using a convertible token coinage was thus a partial success, since it was pursued by several cities for decades. But the medieval hammering technology proved too accessible to counterfeiters, and the cities were plagued by depreciation and recurrent crises, which they met by periodically weeding out counterfeits from the money stock and issuing new types of coins. The turbulent events of the 17th century (vellón inflation in nearby Castile and the bloody war of secession of 1640–52) put an end to this experiment.

The Age of Copper (16th–17th centuries)

To this next came in course the brazen age,

A warlike offspring, prompt to bloody rage,

Not impious yet . . .

Ovid, Metamorphoses I:125-7, translated by Dryden

A substantial technological change occurred around 1550, which made it possible to make coins more immune to counterfeiting. As this innovation diffused across Europe, it was accompanied by the first attempts governments to dissociate the metallic currency from its intrinsic content in a systematic fashion, a possibility now suggested by theory. These attempts took the form of large issues of copper

coinage, issued at first as a substitute for small change, and circulating at much more than its intrinsic content. The extent of these experiments varied across Europe, as well as the consequences. Theorists quickly drew lessons about both the viability and the dangers of fiat currency.

The Technology: Mechanization

The first innovations arose out of the art of medal-making, which began in Italy in the 1430s.[29] Medals, often much larger than coins, were usually cast (and eventually chiseled), but around the turn of the 16th century the demand for high-quality medals had increased and ways to strike medals were sought.[30] This required a mechanized technology both to prepare the larger flanks and to strike them with sufficient force and accuracy. Ultimately, the key innovations occurred among goldsmiths of Southern Germany and Switzerland around 1550. They quickly disseminated to the rest of Europe.[31] Two methods of striking the coins developed: one using a screw-press, the other using two cylinders on which the dies were engraved, thus laminating and striking at the same time. The screw-press came to be adopted in France and England in the 17th century, while the cylinder-press was adopted earlier in Austria, Germany, Spain, Italy and Sweden. In the 18th century, the screw-press overtook the cylinder-press as the main minting apparatus.

We begin with a discussion of the development of each method separately in the next two sections, which leads us to a certain amount of back-and-forth across countries, since some countries experimented with both. In the subsequent sections, we examine the impact made by both methods on governments' policies on small coinage, and the experiments that were undertaken in the 17th century.

[29] This account is based on Cooper (1981) and Wendel (1960).

[30] Some medals were cast and then struck over. This method was imported from Venice to produce groschen in Tirol in 1484 (Wendel 1960, 103).

[31] Earlier developments in Italy by Bramante, Leonardo da Vinci and Benvenuto Cellini (who directed the Rome mint from 1529 to 1534) were not followed upon.

The Screw-Press

In 1547, the French king Henri II decided to reform the coinage of his realm. A first step was taken that same year, by appointing an engraver-general who produced all the punches for making dies in all mints, thus bringing greater uniformity to the realizations of the designs. He also asked his envoys in all countries to report new technologies that could be put to use to produce better coinage. In 1550, he learned from his ambassador in Germany that an Augsburg goldsmith had perfected equipment to produce high-quality coins.[32] The ambassador's brother was sent along with an engineer named Aubin Olivier to Germany. They negotiated the rights to the machines, had them built in Augsburg and brought to Paris. The machinery was set up in a building on the Île de la Cité in Paris, where a water-mill that had been installed in the 1530s for gem-polishing.[33] The Mill Mint (*Monnaie du Moulin des Étuves*) began producing gold coins in 1551, and Olivier became its director in 1556. A rolling mill (powered by the water-mill) created smooth strips of metal or fillets; a drawing bench brought them to the exact width; a hand-activated cutter or punch press perforated the strips into blanks; and a press struck the blanks on both sides. By 1555, Olivier had improved the press by adding a segmented collar to hold the blank in place. During the strike, the collar impressed on the edge of the coin a design or a motto (the collar had to be segmented so as to remove the coin after the strike). The new machines thus mechanized each step in coin-making, and also marked the edges to prevent clipping.

Whether the original Augsburg machinery used a traditional drop-press or a modern screw-press is not clear,[34] but by the mid-17th century, the screw-press was well-developed: its first known depiction is on a painted window in

[32] The details are in Vaissière (1892).

[33] Hocking (1909), Mazerolle (1907, 26–31).

[34] It is usually assumed that the stamping was originally done by a screw-press or fly-press, but there is actual evidence for its use in Paris only after 1600. It is rather unlikely that an Augsburg goldsmith would have had an operating screw-press in his workshop, and more plausibly some kind of drop-press was involved Wendel (1960, 130). A 1676 depiction of the Paris Mint machinery shows both a drop-press and a screw-press. Which mint-master introduced the screw-press is unknown, and no connection with the earlier advances in Italy has ever been found.

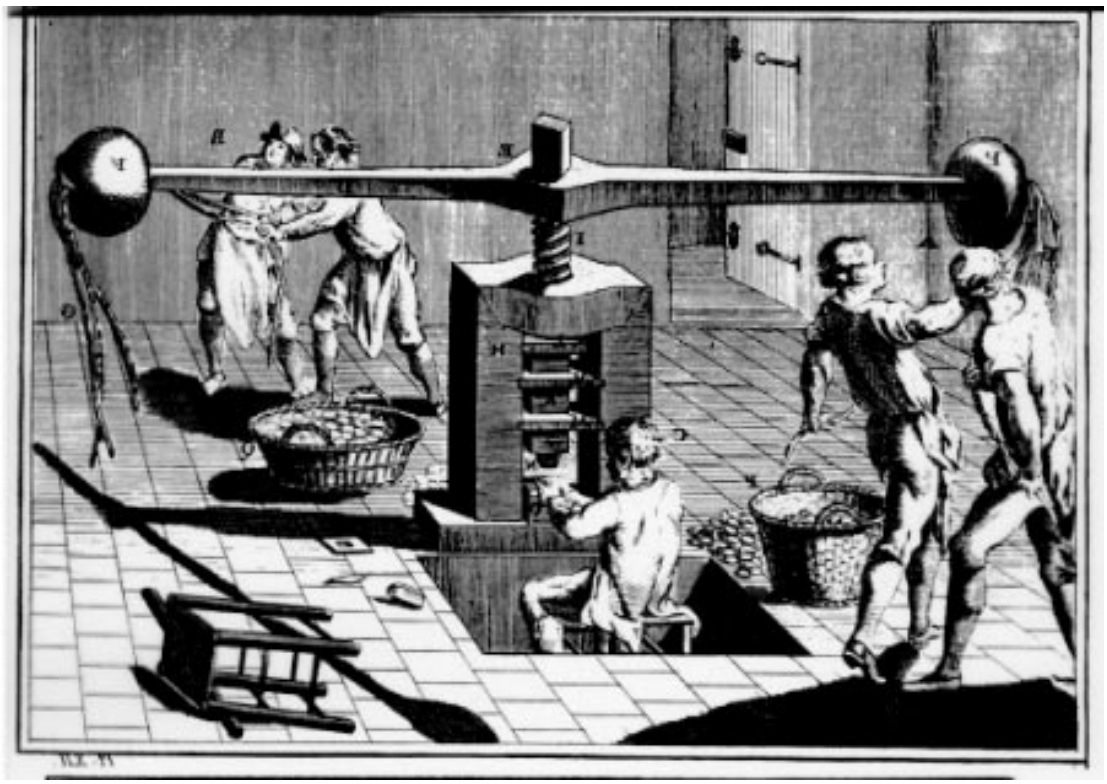

Figure 2: The screw-press (engraving for Diderot's *Encyclopédie*, ca. 1755).

the Constanz mint in 1624. It gained its force from the momentum of two large lead balls (weighing 40 to 150 lb each) at the extremities of a horizontal bar. At the time of its installation in London in 1662, it could strike 30 coins per minute. By the late 18th century, the removal of struck coins and feeding of new blanks had been made automatic; the Paris press took 16 men to operate and could produce 60 coins per minute.[35]

[35] Cooper (1988, 59), Craig (1953, 164), Wendel (1960, 158).

The new mint set up at the Moulin did not function long as coinage mint, however, because of the high costs of operation, and perhaps some initial mismanagement. It was claimed that the wastage amounted to 30%, as opposed to 2% in the hammering process.[36] In 1563, the Mill Mint was restricted by the Cour des Monnaies to medals and tokens. In 1575 its mandate was extended to pure copper coinage. It continued to function in that capacity, producing high quality medals and small copper coins in limited quantities, until 1625.[37] Historians usually attribute this failure to the resistance of entrenched interests among mint-workers and the Cour des Monnaies, although other problems, such as those that England encountered in the late 17th century, may have been foreseen at the time.

England became interested in the new process early on, and in 1554 some attempts were made at imitating the French press. In 1561, a former employee of the French mint named Eloi Mestrell came to England and was allowed to introduce the new technology at the Tower Mint. After 11 years, the machines were found to be ten times slower than the hammering process and the experiment terminated. [38]

In 1630, an engraver from Liége named Jean Warin became director of the Mint-Mill (now called the Medal Mint and located in the Louvre Palace). On the occasion of a general overhaul of the French coinage in 1640, he was allowed to try again to use screw-presses for minting coins, and obtained in 1645 that the mechanized process be used in every French mint. It should be noted that the general recoinage had already been decided upon when the technology was adopted.

Once again, England followed the lead within a few years. In 1649, the Frenchman Pierre Blondeau was invited to England to bring with him the technology: his sample coins were approved in 1651, but the first coins produced with the new method appeared in 1658. The method was extended to the whole

[36] Bodin (1578, 6:???). Cutting a circle out of a square wastes at least $1 - \pi/4$ or 21%.
[37] Mazerolle (1907, 26–34), Blanchet and Dieudonné (1916, 192–5).
[38] Craig (1953, 118–23). Mestrell himself was terminated in 1578 for counterfeiting.

English coinage in 1662. The rolling mills were driven by horses. In his diary for 1663, Samuel Pepys noted that the machinery made coinage more expensive for the king.[39] In England, however, the coins produced for the next thirty years proved to be of such high quality that they were used more as bullion than as money, that is, they were hoarded, melted or exported. By the mid-1690s, the circulating medium was no better, and in fact much worse, than in 1662. It was decided that a general recoinage was needed, as a consequence of the new technology (unlike the French case). In distinction with France, the recoinage was carried out at government expense, and the worn and clipped coins were exchanged one-for-one with the new milled coinage. [40]

The screw-press was not widely diffused until after its nearly simultaneous adoption in England and France: it was adopted in Brandenburg soon after the peace of Westphalia in 1648, and by the Netherlands in 1671. Spain switched to the screw-press in 1728.[41] Thus, the screw-press, which ultimately proved to be the superior technology, was not fully adopted for a hundred years after its appearance; largely, it seems, because of a reluctance to accept its high investment costs, both physical and in terms of acquisition of skills.

The Cylinder-Press

While Henri II of France was actively searching for a new technology, Charles V, German Emperor and king of Spain, was inspired to do the same. One of his advisers, count zu Solm-Lich, recommended mechanization to reduce minting costs; in 1551, he proposed the principle of a cylinder-press, similar to the rolling presses already in use by goldsmiths to produce flat strips of metal. The cylinders themselves would be engraved with the coin die; the coins would be cut out of the stamped strips afterwards. Horses or water-wheels were to provide

[39] Pepys (1970, 4:147).
[40] Craig (1953, 184–97). See contemporary discussions by Lownde and Locke.
[41] Walther (1939). The screw-press technology is also known to have been transferred to the small kingdom of Navarre (soon to be united to France), where a similar mint was set up by a former engraver of the Paris mint in 1556. Wendel (1960, 132) mentions that two German brothers obtained a patent for a screw-press to be used in minting from the king of Poland in 1578, but nothing further is known.

power. The Emperor's brother Ferdinand, count of Tirol, showed interest and asked his mint officers in Hall to investigate the possibility.

The first working cylinder-press, however, was set up in Zürich in the early 1550s, by two goldsmiths.[42] The mechanism had the advantage of both laminating and stamping the metal at once. A disadvantage was that it was necessary to engrave oval dies. Also, the coins often came out slightly warped, which made serrating of the edges impossible. In spite of these flaws, the process proved very popular. The Swiss inventors set up a partnership to develop the new invention commercially and export it abroad; they obtained a patent for all of Germany. Ferdinand bought it for Tirol and it was installed in Innsbruck in 1568. Austria would remain faithful to the cylinder-press until 1765.

The cylinder-press was soon adopted throughout Germany and beyond: Heidelberg in 1567, Cologne in 1568, Augsburg in 1572, Dresden in 1574, Danzig in 1577, Nyköping (Sweden) in 1580, Madgeburg in 1582, Hamburg in 1591, Saalfeldt in 1593, Rostock in 1594, Osnabrück in 1597, Münster in 1599. It reached Poland in the late 16th century, where the Göbel brothers secured a patent and exported it to Königsberg, Riga, Denmark. Before 1600 it had also reached Clausthal-Zellerfeld in Hannover near the mines of the Harz, Berlin and Strasbourg. Sweden began using cylinder-presses in 1625 in Kopparberg, near its large copper mines.[43]

A variant of the cylinder-press developed in the 17th century: instead of engraving a whole cylinder, two mushroom-shaped pieces were engraved and inserted in slots of rotating axles. This design was known as Taschenwerk, and it required pre-cut oval-shaped blanks (their passage between the dies made them round). It was introduced in the early 17th century in France and England, but did not take root. A man named Nicolas Briot had begun his career as mint-master in Northern France and Lorraine, and traveled extensively to Germany, where he learned of the various techniques used there. He became director of the

[42] See Hahn (1915, 19) and Newald (1897) for the early development of the cylinder press.

[43] Walther (1939), Wendel (1960, 134).

engraver of the mint in 1606, and in 1620 obtained the lease for the Paris mint. In 1617 a trial of his proposed minting device was carried out before French officials, but resulted in failure: wastage was high and the coins were not of good quality.[44] In 1625, he left for England where he became chief engraver of the mint. In 1629, he was allowed to experiment with machinery which he had been using to strike medals; he was also put in charge of producing pure copper coinage at the mint in Edinburgh, but neither attempt proved conclusive. In 1639, he tried again in Scotland with silver coinage: he used a Taschenwerk for large denominations and a screw-press for small denominations. The machinery was in part moved by horses. The costs were substantial, and the machines apparently remained experimental. Later, during the Civil War, Briot (who died in 1646) minted coins for the Royalists using cylinder-presses.[45]

From Germany, the screw-press technology quickly spread to Southern Europe. Mechanization came to Florence in 1576, when machinery driven by a water-mill was installed in a new Zecca on the banks of the Arno, near Santa Croce. The machinery was imported from Germany, and operated by German engineers who proved to be excellent workers and great consumers of Chianti wine.[46] Rome had similar equipment by 1581.That year, Philip II of Spain asked his cousin the archduke Ferdinand, count of Tirol, to send him a copy of the Innsbruck machines, and the archduke obliged by sending 6 German craftsmen who built them in the Segovia mint, henceforth known as the *Ingenio*.[47] The first coins, silver reales, were issued in 1586.

[44] See Poullain (1709) for the minutes of the trial.

[45] Craig (1953, 147–50), Mayhew (1992b).

[46] Cipolla (1990, 233). Only silver coinage was produced in the new mint; gold was produced in the old Zecca. Cipolla does not specify the method used, but Wendel (1960, 134) states that it was a cylinder-press.

[47] The story of the Segovia Ingenio is told in Rivero (1918).

The Coinage of Pure Copper

The 16th century saw the emergence of a technology for producing coins with high fixed costs and a large and standardized output. Aside from residual variations due to the imperfection of hand-produced dies, coins were round, sharply imprinted and nearly identical. These characteristics presented high barriers to counterfeiting. It became possible for governments to produce coins whose intrinsic content was considerably lower than their face value, in particular pure copper coins. [48]

Several countries experimented with the new technology by using it for small change. However, their approaches differed. Spain[49] began issuing token copper coinage in 1596, for reasons of efficiency, but soon embarked on a large-scale fiat money experiment that lasted several decades. England issued its first copper coinage in 1613 (Spufford 1988, 372), but remained leery of token coinage and maintained its coins close to full-bodied. France, which first experimented with mechanized minting of small change in 1577, displayed ambivalence, and occasionally started down the road of large-scale token issues, without following through. Finally, several other countries experienced episodes of replacement or displacement of large coins by token coinage; in Russia, this resulted from an outright policy decision to replace silver with overvalued copper coins, whereas the German experience resulted from a lack of adequate small coinage, to be filled by competing states vying for seigniorage revenues.[50] These experiments often resulted in large inflations, and we examine them in turn.

Other students of the period have noted the prominence of copper in 17th

[48] These were not the first pure copper coins. The first examples appeared in Naples and in Venice in 1472, and later in the Spanish Low Countries in 1543. The Italian copper coins were full-bodied and were issued to drive out over-valued currency imported from neighboring countries (Grierson 1971).

[49] more precisely Castile; the kingdom of Aragon, while part of Spain, had its own monetary system that was not affected by the events in neighboring Castile.

[50] Although the use of the new minting technology is not a clear factor in the German and Russian cases, both illustrate the difficulties of governments grappling with the problem of circulating fiat coinage and the consequences.

century monetary history, but explained it differently. Spooner (1972, 41) writes that "it was not possible, actually, for silver alone to meet the total monetary demand. As a result, copper achieved exceptional success, promoted almost to the status of a precious metal. . . . There was a temptation, and perhaps an obligation, to use [coins of pure copper] when bullion was relatively scarce." Our interpretation of the 17th century "Age of Copper" will be very different.

The Castilian Experience (1602–60)

Philip II of Spain explicitly recognized the impact of the new technology in the royal decree of 1596 by which he announced the production of pure copper coinage in the cylinder-presses of the Segovia mint (Maria del Rivero 1918–19, document 14). He justified his decision as follows: "we have been advised by people of great experience, that the silver which is put in those billon coins is lost forever and no profit can be drawn from it, except in their use as money, and that the quantity of silver which is put to that use for the necessities of ordinary trade and commerce in this kingdom is large. We have also been advised that, since we have established a new machine (*Ingenio*) in the city of Segovia to mint coins, if we could mint the billon coinage in it, we would have the assurance that it could not be counterfeited, because only a small quantity could be imitated and not without great cost if not by the use of a similar engine, of which there are none other in this kingdom or the neighboring ones. And it would thus be possible to avoid adding the silver." Until then, copper, silver and minting costs each represented a third of the face value of vellón (billon) coinage. With Philip II's decree, the silver was withheld and the copper content reduced.

Philip II had efficiency in mind: he ordered that the new copper coins be issued only to retire existing small denomination coins. In terms of the model of Sargent and Velde (1997), the aim was to replace m_2 (small denomination coins) with token coinage, but to preserve the mechanism with its melting and minting points for providing of m_1 (large denomination silver coins). Retaining the mechanism for supplying m_1 would keep the price level within the appropriate

melting and minting points so long as some large denomination coins continued to circulate. But Philip II's successors Philip III (1598–1621) and Philip IV (1621-64) saw that the cylinder press offered opportunities to enhance revenues, and in the process increased m_2 to the point that it replaced m_1.[51] This released the price level from the constraints imposed by the melting-minting points for m_1, and unleashed the quantity theory cast in terms of m_2 as the determinant of the price level. Figure 3 and Figure 4 record some of the results of the Spanish monarchs' experiments with token coinage. Figure 3 graphs the real and nominal values of the stock of copper coins. Figure 4 displays how the market value of a particular coin (the vellón *cuarto*) fared relative to its intrinsic value over the period.

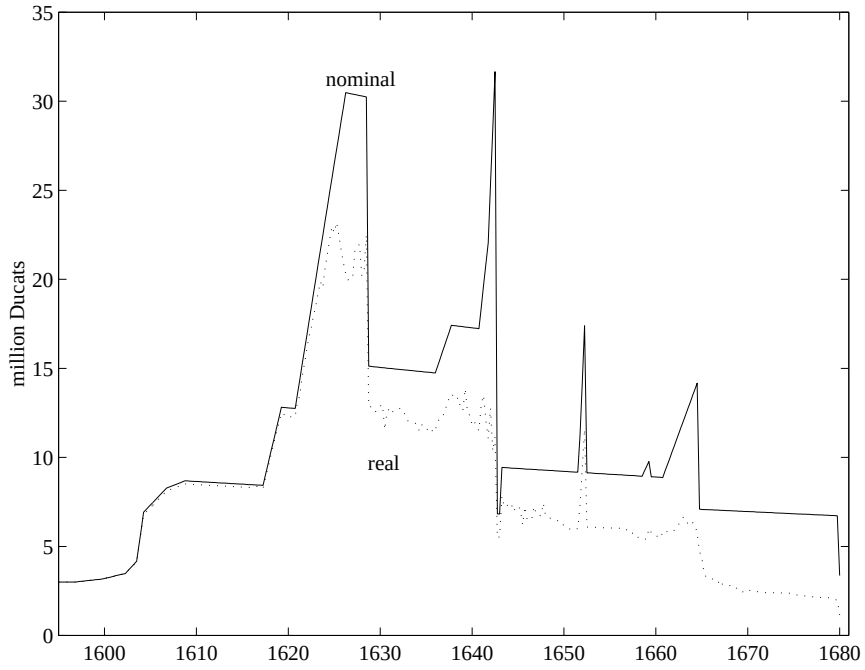

Figure 3: Nominal value (in copper mr) and real value (in silver mr) of the vellón stock, 1595–1690. 1 ducat (D) = 375 maravedis (mr).

[51] The story of vellón inflation in Castile is told in Hamilton (1934), Domínguez Ortiz (1960), Motomura (1994), and Velde and Weber (1997).

Three money supply operations govern these movements: coinage, restamping, and devaluation. By *coinage* we refer to the government's making fresh coins out of copper purchased for that purpose. By *restamping*, we refer to the following offer made by the government: bring in two coins marked x maravedis,[52] let the government stamp both coins with $2x$, allow the government to keep one and leave with the other.[53] By *devaluation* we refer to a sudden announcement by the government that coins marked $2x$ are now worth x (i.e., a reduction in e_t in the model of Sargent and Velde 1997). The purpose of the coinage and restamping operations was to raise revenues for the government, in the process increasing the nominal and also the real stock of vellón coins. Devaluation was a tool to be applied after so many vellón coins had been issued that all silver had been driven from circulation and a pure quantity theory cast in terms of token coins determined a price level exceeding the 'melt down point' for the silver coins. The purpose of devaluation was to drive the price level back to a level low enough that silver not only would not be melted but actually coined, thereby restoring the restraints on the price level associated with the melting-minting points.

Figures 3 and 4 show the workings of these operations in succession. In 1602, the government decided to reduce by half the copper content of the small denomination coins it was producing, and observed no depreciation (in Figure 4, the coin's intrinsic value was reduced to $1/8$ of its market value). It then decided to recall the coins minted until 1602 and restamp their value by a factor of 2. No inflation ensued, and the government of Castile was encouraged to mint large quantities of the new coins, not just in Segovia but in the other mints as well, even though they continued to rely on the medieval technology, producing poor quality coins known as 'thick billon' (*vellón grueso*).

By 1626, the vellón coinage had completely replaced silver as medium of

[52] The maravedi was the unit of account in Castile.

[53] Strictly speaking, such an operation leaves the private agent indifferent. To break the indifference, the mints of Castile offered a small premium, in the form of a travel cost allowance.

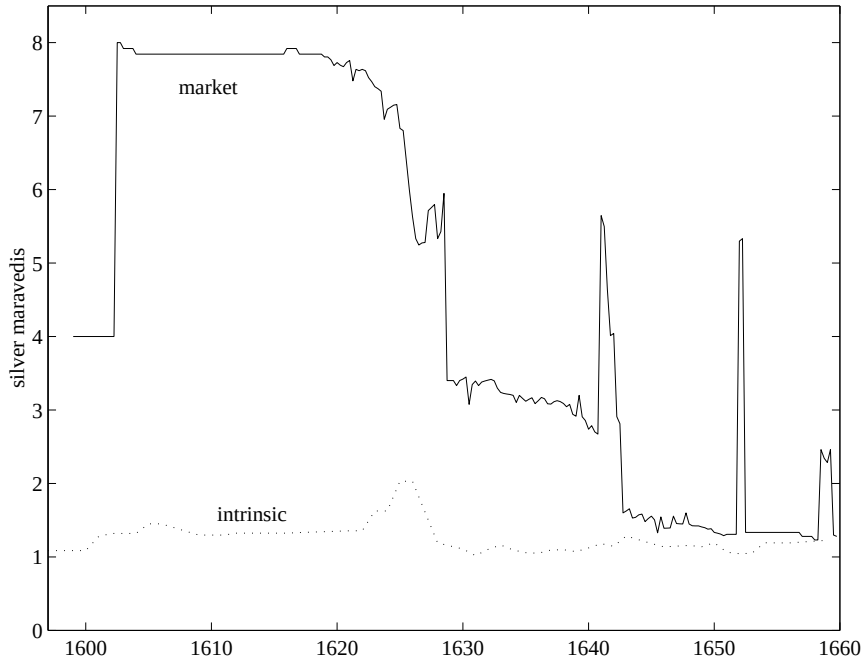

Figure 4: Market value and intrinsic value (in silver mr) of a vellón *cuarto* coin, 1597–1659.

exchange, and inflation set in.[54] A comparison of nominal and real balances of the vellón coinage in Figure 3 indicates that by 1626 an upper bound on real balances had been reached (which corresponds to total money demand in the model of Sargent and Velde 1997), and further issues only created inflation.[55] Alarmed policy makers halted the minting and deliberated for two years about the best way to stem the inflation. They started an open-market operation to exchange copper coins for bonds but soon cancelled it. That they seriously considered this operation shows that they understood how the price level was under sway of the quantity theory cast in terms of the vellón coins. Eventually, in 1628, they used devaluation: they halved the face value of the copper coinage overnight. This brought the market exchange rate between copper and silver

[54] Hamilton (1934, ???) states that 95% of transactions used vellón. Castilian vellón even began circulating in bordering areas of France in 1626 (Spooner 1972, 178).

[55] Velde and Weber (1997) estimate the pre-existing silver stock at 15m to 25m ducats.

coins part but not all of the way back to its pre-1602 value: the premium on silver fell from 50% to 18% (in Figure 4, the market value of a 4-maravedis coin did not return to 4 mr in 1628).

Castile did not issue any more copper coinage until 1660, but it carried out four restamping operations to multiply the face value of the copper coins by 2, 3 or 4. Each of these restamping operations was soon followed by a downward devaluation of the copper-silver exchange rate. These show up in the downward movements in nominal values in Figure 3 and Figure 4. Each restamping operation succeeded in generating revenues, as individuals brought in coins to exchange them unit per unit, affording seigniorage rates of $1/2$, $2/3$ or $3/4$. But the government found that the revenues it could raise were diminishing. In Figure 3, it is apparent that the real balances of vellón fell over the course of time.

From 1660 to 1680, Castile issued small coins made of a mixture of copper and 7% silver, this time using the cylinder-press technology in all mints. Initially, the government tried to give the coins a face value above intrinsic content, but depreciation forced it to abandon that project, and the coins were issued at close to intrinsic value, like medieval billon. Extensive counterfeiting (in spite of the use of the new technology) ultimately forced the government to abandon billon altogether: its cost advantage had already been dissipated. After 1680, the small coinage in Castile was, like elsewhere in Europe, full-bodied copper, with a return to the hammering method. Not until the advent of the French Borbón dynasty were the hammers and the cylinder-press replaced with imported screw-presses in 1728.

The shape of the time series for real balances in Figure 3 bears a remarkable resemblance to the graph for real balances of the French paper assignats issued during the French Revolution. (The different time scales show a much more rapid pace of events during the French Revolution.) In both cases there initially occurs a build up of real balances of the token currency, accompanied by only modest depreciation of the token money. In both cases, real balances of the

token currency eventually climb to constitute the entire stock of real balances, driving out other monies, thus threatening to activate the quantity theory. In both cases, there emerge periods of persistent inflation accompanied by declining real balances of the tokens. Thus, in the Castilian example, the period from 1602 to the early 1620s is one where one token currency replaces another, with little observed inflation, as occurred with the introduction of a paper currency during the French Revolution (Sargent and Velde 1995).[56] In the French case, the subsequent period of declining real balances of the token money exhibited all of the features of a classical hyperinflation along lines described by Cagan (1956). It is intriguing to speculate that related forces account for the long decline in real balances in Figure 3, because the repeated pairings of restamping with soon to be followed devaluation operations must eventually have been come to be expected, prompting people to economize on real balances of m_2. But the model of Sargent and Velde 1997 is not set up in a way that permits us to simulate this mechanism.

France and England in the 17th century

In England, the provision of pure copper coinage in an official form began in the 17th century. From 1613 to 1644, there existed a royal license to manufacture token farthings, but the tokens were never legal tender. The monopoly was owned by various people in turn; they used mechanized minting even as the Royal Mint continued to hammer coins, until the Puritans abolished the monopoly.

In France, the notion that mechanized minting allowed a fiduciary coinage seems to have dawned at the same time. The mechanized mint had been set up in 1552; in 1575, it produced the first pure copper coins (the smaller denominations had until then been made in billon); the intrinsic content was worth about 45% of the face value. To quote Blanchet and Dieudonné (1916, 172): "The date of this reform is important: in distinction with medieval currency which, however

[56] A notable difference is that, in the Castilian case, the convertibility of the token coinage was an equilibrium outcome, rather than a feature of the environment.

alloyed, had never had value but for its content of fine metal, we see the birth of subsidiary fiduciary coinage, thanks to the progress in public credit, as well as to a sharper understanding of the relative roles of metals in circulation." It is important to note that these copper coins were produced in the mechanized mint (ibid., 337).

The minting of pure copper coins continued on a rather limited basis. In 1596, it was decided that all pure copper coinage would be made in the Mill Mint exclusively, and very little was produced. From 1602 to 1636, however, the French king began granting private individuals licenses to produce copper coins using presses, just as in England, although they were legal tender. The licenses limited the total coinage, and the Cour des Monnaies tried to restrict these issues as much as it could, so that they remained very limited.[57] Throughout this period, imitations of French copper coinage were being actively minted in foreign enclaves in the French kingdom (Dombes, Orange, Avignon); typically, they circulated in rolls (Spooner 1972, 178, 186).

When, however, mechanized minting was extended to all mints in 1640, new emissions of pure copper soon followed, small amounts in 1642 and 1643, and much larger ones between 1653 and 1656, at a time of extreme political crisis.[58] The minting was subcontracted to private entrepreneurs who established presses in small towns with water-mills. The amounts remained small, however, at least in comparison with the Spanish experience. The output of 1653–6 only represented the equivalent of 1.6m Spanish ducats and amounted to 2 or 3% of the French money stock.

France thus followed a similar course to England in some respect (handing out limited monopolies to produce copper coins with presses), similar to Spain in others (large quantities of fiat copper), in spite of the numerous warnings of monetary officials.[59]

[57] Spooner (1972, 174–8, 185–92, 336–9).
[58] The output was 0.3m livres in 1642–3 and 7.3m livres in 1654–6.
[59] Spooner (1956) documents the opposition of the Cour des Monnaies.

Inflationary episodes in Germany and Eastern Europe

In Germany, efforts by successive Emperors since the 15th century to coordinate the coinage policies of the many constituent states of the Empire culminated in an imperial mint ordinance (*Reichsmünzordnung*) of 1559. This left the responsibility for minting coins to selected group of princes, but fixed the intrinsic content of coins throughout the whole denomination structure, and made small coins full-bodied. This arrangement led the official mints to produce only large denomination coins (silver Thalers and Guldiner) and caused a shortage of small change that was increasingly met by unauthorized mints that produced light-bodied coins. Over time, these coins became lighter, so that by 1610 they were already 20 to 25% lighter than prescribed in the mint ordinance.

When the Thirty Years War began in 1618, the stage had been set for what became known as the *Kipper- und Wipper Zeit*, meaning 'the clipping and culling times'.[60] Throughout Germany and the Habsburg lands, local princes as well as private mints competed with each other and produced increasingly debased petty silver coinage (Groschen, Kreutzer and Pfennigs), driving the intrinsic content to $1/8$ of the amounts prescribed in 1559. Some states even issued pure copper coinage. People queued at the mints to turn their copper pots and pans into coins. The large coins remained unchanged. Their prices in terms of the small coins are tracked in Figure 5. Commodity prices also increased greatly, although not quite as much. The inflationary episode ended abruptly in 1623, when the princes' deteriorating tax revenues forced them to return to a better standard. However, another episode of inflation, less spectacular and more drawn out, was to take place in the late 17th century (the so-called second Kipper- und Wipperzeit).

The *Kipperzeit* of 1619–23 reflected the problem of small change. The

[60] Gaettens (1955, chapter 4), Rittmann (1975, Chapters 9 to 12), Sprenger (1991, chapter 7) for general surveys and references to the numerous regional studies. A brief treatment in English is Kindleberger (1991). This episode has attracted little interest in the English language literature, even though German writers called it 'the Great Inflation' until it was superseded in 1923.

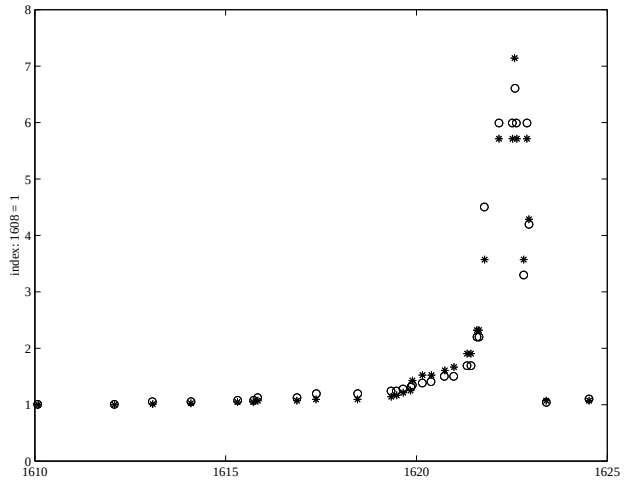

Figure 5: Price of the the Gold florin (circles) and the silver Thaler (stars) in terms of Kreutzer coins, Bavaria. Source: Altmann (1976, 272–3).

1559 ordinance's strict adherence to the concept of full-bodied coinage throughout the denomination structure opened a gap that was filled by unauthorized and uncontrolled coinage. Under the fiscal pressures of the Thirty Years War, this coinage developed much as the Castilian vellón had.[61] The scale of inflation evident in Figure 5 even surpasses Castile's experience, with the price of silver coins tripling from March 1621 to March 1622. Minted quantities for all of Germany cannot be known, but there is information for Saxony, a major state and important silver-producing area. In the twenty years preceding the inflation, Saxony minted 0.4m fl. per year, almost all in large silver coins. During the four years of the Kipperzeit, at least 12.5m fl. in small coins were minted, 5.5m fl. in Dresden alone. During the following 28 years, 0.1m in large silver coins were minted per year (Wuttke 1894, 142).

As Richard Gaettens wrote (1955, 95): "From the point of view of monetary history the Kipperzeit had undoubtedly also a positive side. Indeed it became apparent that alongside the main currency a fiduciary money was needed for small change. . . . The development of subsidiary coinage received in the

[61] The similarity with the Castilian inflation is noted by Redlich (1972, 12).

Kipperzeit its decisive impulse."

In the second half of the 17th century, large issues of small coins and a consequent depreciation of the large currency recurred in Eastern Germany and in Poland. While engaged in a war against Poland, the Russian Czar began to mint pure copper imitations of silver rubles in 1655, and decreed that they should exchange at par with the latter. Initially successful, this currency collapsed after a few years. The pattern shown in Figure 6 (stable exchange rate for several years, followed by a rapid collapse) seems less puzzling when compared with the Castilian experience. In 1663, the copper rubles were bought back by the mints at 1% of their face value.[62]

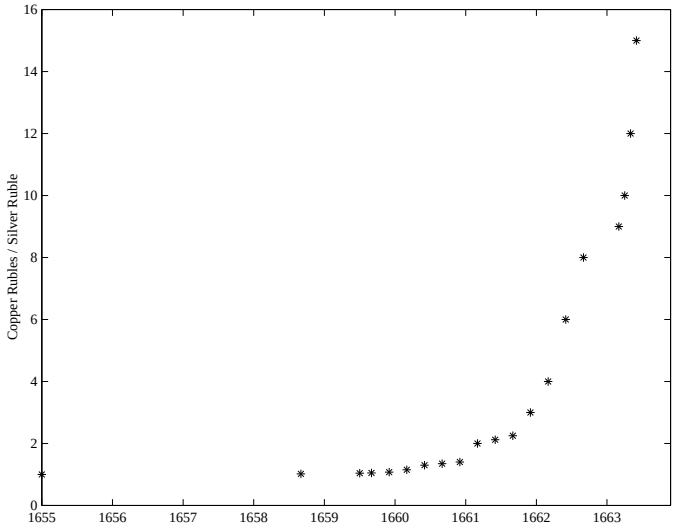

Figure 6: Exchange rate of copper rubles to silver rubles, Russia (1655–63). Source: Chaudoir (1836, 1329–30).

Mechanization came to Sweden in 1625. The following year, Spain stopped minting copper. An unintended consequence of Spain's monetary reform was to export inflation to Sweden. Here is how this happened. When Spain withdrew

[62] See Chaudoir (1836, 128–30) and Bruckner (1867) on Russia, Bogucka (1975) on Poland.

from copper, it caused the demand for Swedish copper (the biggest producer in Europe) to collapse, because Spain had been consuming the equivalent of half of Sweden's copper output (Wolontis 1936, 221). The Swedish king, Gustavus Adolfus, repeatedly pressed his French ally to buy Swedish copper and to mint it. In 1636 he almost succeeded, but the project was blocked at the last minute by the French Cour des Monnaies (Spooner 1972, 189–90). To promote demand for Swedish copper, Sweden then decided to move to a copper standard itself, which it retained until the mid-18th century when it went to a paper currency. The Swedish experience differed from the Spanish in that the coins were full-bodied rather than fiduciary—its aim was to enhance the demand for copper; a full bodied coinage achieved this aim more aptly than did a token one. The inflation that occurred in Sweden was entirely due to a declining copper content of the unit of account (Heckscher 1954, 88–91).

A final example comes from the Ottoman Empire. In the 1680s, a Venetian convert was hired to construct screw presses and replace the old hammering method. The first use of the new machines was to produce massive amounts of copper coinage from 1687 to 1690, when the *mankur*, whose copper content was worth about 0.14 silver *âkçe*, was ordered to pass for 1 *âkçe* (Sahillioğlu 1983, 289; Pamuk 1997). The Ottomans were thus using the same methods as the Castilians to finance their own, large wars (and achieved the same degree of success in the prosecution of those wars).

Monetary Theory

Quantity Limitations

Gasparo Thesauro (1607) gave an early statement of the risks inherent in excessive issues of small coins. He attributed variations in the value of money to three possible causes: fluctuations in the gold/silver ratio, debasement of the petty coinage, and excessive issue of petty coins: "when too much copper coinage is issued or imported from elsewhere, the price of the better coin is always altered, and this variation is detrimental to the creditor if he is repaid in that money; for, even if the quantity of copper coinage corresponds to the correct valuation in gold or silver, because of the tediousness of counting, the inconvenience of storage and the cost of transportation, some loss results for the creditor, and therefore it is thought that good coins of gold and silver correspond to a larger quantity of copper coins than the exact valuation requires, and thus their value changes. To avoid this alteration it is good that an insufficient amount of small and copper coinage be made, since it is customarily made for small purchases of food and to supplement large coins, not to repay creditors; the same goes when inferior foreign coins are brought in." Thesauro's main motivation was price stability: money "is everlasting, and should have a fixed proportion, since it is used to value all things, and not be valued by others: the measure of all things." Thesauro favored limiting legal tender and not allowing repayment of debts in small coins. He endorsed a Portuguese ordinance limiting the use of small coins to a fourth of a debt, and an ordinance of Ferdinand limiting their legal tender to 25 gold coins. [63]

In Naples, A. Serra (1613) suggested issuing small money "in quantities

[63] Thesauro (1609, 629–33), partially quoted in Cipolla (1956, 30). In fact, legal tender limitations on small change, whether full-bodied or not, became more common. Aragon limited legal tender in 1494 soon after the introduction of convertible token coinage. In England between 1613 and 1644, the copper coinage made under license was not legal tender. In 1672, royal farthings were limited to 6d (Carothers 1930, 12). In France, the new copper coins of 1577 legal tender for a third of a debt up to 100 sols. In Germany, the Imperial ordinances of 1559 and 1576 limited small change to 25 florins in legal tender. In the United Provinces, in 1622, it was limited to 1/24 of sums over 100 guilders (Monroe 1923, 97).

sufficient for making change depending on the size of the state"; he also advocated that it be made "not of alloyed silver but of pure copper, in which only the form and not matter gives value, because this would result in a considerable profit for the prince without generating any of the inconveniences, and in any case it will be very easy to determine the quantity which does not generate them." But he conceded that it would be very easy to counterfeit, and did not say exactly how the correct quantity could be determined.

In Germany, Faust (1641) proposed to coin petty money according to need, and not make it legal tender, with the explicit intention of thereby limiting its quantity. His aim was to avoid debasements.

Petty (1682) estimated the quantity to which small change should be restricted: one is a per household figure (12d; recall that Petty also estimated total population), another was based on the denomination structure and the need to make change. He also admitted that the coins could be "debased"[64] to a limited extent, and the seigniorage accrue to the king. Petty regarded privately issued trade tokens (a common phenomenon in England at the time) as not base so long as they were convertible; but he did not propose that state-issued small change be convertible. (Monroe 1923).

Lessons from the Castilian Experience: Fiat Money

In Spain: Juan de Mariana (1609)

Spaniards were among the first to draw lessons from the vellón experiment. The most famous was the Jesuit Juan de Mariana (1536–1624), whose *De Monetae Mutatione* was written between 1603 and 1606 and published in Cologne in 1609 to avoid royal censure (the Inquisition nevertheless paid him a visit).[65]

[64] Monroe's words: does he mean fiduciary?

[65] See Mariana (1994) for a modern critical edition of the Latin text with German translation and Laures (1928) for an English summary and analysis. A contemporary Spanish version has also been republished recently (Mariana 1987). Contemporary Spanish economic thought is discussed by Gracie-Hutchison (1978, 1993).

Though he came down against the vellón experiment, in the careful manner of the Jesuits, Mariana carefully lays out arguments in favor of the vellón experiment as well as against; he even carefully refutes what he takes to be weak reasons against the experiment. In doing so, he is probably describing the controversies between the advisers who pushed the kings of Spain toward that policy, and their adversaries. Among the advantages cited were the fact that silver was no longer wasted in making coins; that the silver received from the Indies, instead of going to maintain the money stock, could be spent by the king for his war-time supplies; that without a stock of silver coins as a potential reserve to settle the balance of trade, trade and production would eventually have to adjust to make deficits less likely, thereby turning the balance of trade in Spain's favor and stimulating production; that the copper money was lighter and easier to transport, and that its cheap provision would lower the rate of interest and stimulate agriculture and industry.

Mariana disposes of some arguments against the vellón. For example, he admits that the over-valuation of copper coins will provide huge incentives for counterfeiting, but counters that new technology can resolve the problem, and recommends that coins only be made in the Segovia mills. He notes that the arguments on balance of trade and stimulus of the economy can be made to go either way, and "since they can go in either direction, they have force in neither."[66]

Among his own main objections against the policy is the fact that laws limit the quantity of small change, and for good reason, because small change should only be used for small transactions, and while copper coinage is necessary in limited quantities, an excess will lead to a disappearance of silver. He is also motivated by the historical observation that debasements have always led to a rise in prices: he assimilates the issue of vellón to a debasement and predicts that excessive quantities of copper coins will make them worthless. He notes that in some places, a premium of 10% is already observed on silver coins, and elsewhere

[66] Mariana himself claims to prefer historical examples to a priori theorizing.

5%. Price controls will be set by the king, but individuals will either ignore them or abstain from trade. Ultimately, the king will be forced to demonetize the coins, or else revalue them, so that "overnight, as if in a dream, the owner of 300 ducats in this money will have 100 or 150." He sees the projected sequence of inflation and deflation as disruptive to trade and contracts, and therefore to the king's tax revenues. He also views the high seigniorage rates of $1/2$ in the restamping operations as immoral, because in his view the king has no right to tax his subjects without their explicit consent, and notes that such high tax rates would never be tolerated on any other tax base. The worst consequence he predicts is general hatred of the king: quoting Tacitus, he recalls that "everyone claims prosperity for himself, but adversity is blamed on the leader."

In France: Henri Poullain (1612)

The Frenchman Henri Poullain, an official at the Cour des Monnaies, advised the government on monetary policy.[67] In the course of his duties, he dealt repeatedly with proposals by private individual to mint copper coins under license. In a 1612 memorandum on one such proposal, he wrote: "In any state, depending on its size, productivity and endowment in things useful to human life, there must also be a proportionate and definite quantity of coins, for the needs of the trade and commerce which takes place within it." He estimated the quantity of money in France and the quantity of copper coins recently minted, and noted that, in 1596, tax collectors were receiving large amounts of small coins, from which he concluded that the quantity of small coins in circulation was more than sufficient for trade. He then distinguished between foreign trade and domestic trade, and supposed that the total money supply is used, half in one and half in the other. He asserted that copper could displace large coins in domestic trade: "When the prince mints quantities of billon or copper coins, such bad coins remain in his state for the domestic trade, and the good silver and gold coins are taken out of the kingdom by its residents to purchase foreign goods. Thus bad coins hide and expel good coins; because within the state they

[67] Some of Poullain's writings were published (Poullain 1709). Others are discussed by Harsin (1928).

stand in for, and serve just as well, as the good ones; no more or less than in a card game, where various individuals play, one avails oneself of tokens, to which a certain value is assigned, and they are used by the winners to receive, and by the losers to pay what they owe. Whether instead of coins one were to use dried beans and give them the same value, the game would be no less enjoyable or perfect."

Poullain explained how copper coins were more expensive to make, and could not contain more than a third of their face value in metal: "they cannot pay or receive any price alongside the good coins of gold and silver without resulting in (leaving aside all other problems) an increase in the prices of all sorts of commodities, as it always happens with such devaluations." He cited the example of Spain's vellón coinage and the "horrors" that ensued, and also referred to Juan de Mariana's 1609 treatise.

In a separate memorandum on the Castilian "monetary disorder" in 1612, he explained the mechanism by which prices increase. (Please note that as shown in figure Figure 3, the "monetary disorder" to which he refers is the substitution of light copper coins for full bodied coins; in 1612, the vellón experiment was still working well in that vellón coins were not going at discount.) "Any state is always in need of a moderate quantity of billon or copper coinage". But an excess of such coins brings about a general rise in the price level: as gold and silver coins become rarer in proportion with the production of bad coins, so the price of imports rises. Eventually domestic goods also rise in prices, because "in any state there are always foreign goods of the same kind as the ones made within it".

In 1683, Geminiano Montanari, a mathematician and astronomer in Padua, wrote: "If a state had no commerce with the other states and lived solely on its own productions, as China and a few others have done for so long, the prince could set the value of money as he pleased, and make it of whatever content he wished." He cited the case of Chinese paper money described by Marco Polo. "But if a prince wants his own coins of gold and silver to be accepted by for-

eigners, so that his subjects can trade with them, he cannot value them if he does not set the right content." In this case, the prince can only collect a small seigniorage, inferior to the cost of transporting metal to neighboring states. But he is not so constrained for small change, and "it is clear enough that it is not necessary for a prince to strike petty coins having metallic content equal to their face value, provided he does not strike more of them than is sufficient for the use of his people, sooner striking too few than striking too many. If the prince strikes only as many as the people need, he may strike of whatever metallic content he wishes." In case of over-issue, the small coins will replace the large coins, and merchants dealing with foreigners will need large coins, for which they will have to pay a premium, and prices will increase. The prince's latitude in setting a high seigniorage rate is limited by the threat of counterfeiting, although the death penalty which is imposed on counterfeiters means that people willing to counterfeit will require much higher wages than legal moneyers.[68]

Laisser-Faire or Monopoly: England's Hesitations

English coins had always been made of sterling silver (except during the Great Debasement of 1540–60), and the smaller coins, from the farthing to the penny, had become too small to be produced and handled. By the mid-16th century, royal coinage of these smaller sorts ceased altogether. Until 1816, when the issue of convertible token coinage was organized, England alternated between three regimes for the supply of small change: private monopoly of inconvertible token coinage, government monopoly of full-bodied coinage, and laisser-faire resulting in private competition in the supply of convertible token coinage. Each time the government put an end to the laisser-faire regime, it did so immediately after adopting a new technology.

Private Monopoly The private monopoly regime lasted from 1613 to 1644. A

[68] Montanari (1804, 104–119). partially quoted in Cipolla (1956, 29).

royal patent granted some individual the exclusive right to manufacture copper farthings. The patent set a minimum weight for the coins, but that minimum was low: at the current price of copper, the coins' intrinsic content was no less than 4% of face value. The coins were thus issued at a high rate of profit, which was shared with the king. The coins were not made legal tender: the king's proclamation of 1613 said that the coins were 'to pass for the value of farthings . . . with the liking and consent of his loving subjects.' Some patents instructed the manufacturers to rechange the tokens into sterling for a year (1613), establish an exchange office (1617), to 'relieve' anyone 'overburdened' with coins (1625). Predictably, the coins were counterfeited, and in the 1630s counterfeits were offered at 24s to 26s for 20s sterling. The design was changed, and a brass insert added to the coins to make them harder to counterfeit, in 1636; the patentees were again instructed to exchange tokens for sterling, but it is not clear whether they did. The monopoly was abolished by Parliament in 1644.[69]

Laisser-Faire The laisser-faire regime occurred several times: from the mid-16th century to 1613, from 1644 to 1672, and from the 1740s to 1817. Each time, the government desisted from making its own coins, but did not seriously interfere with private suppliers of coinage, or even gave its official assent.

Private suppliers were numerous. In the late 16th century, up to 3,000 London merchants issued tokens (Craig 1953, 139–40). Citing complaints 'against the tokens of lead and tin, generally coined and uttered instead of such small monieds by grocers, vintners, chandlers and alehouse-keepers,' a projected proclamation of 1576 announced the issue of royal copper farthings and half-pence, providing that 'such cost and charge should be employed thereon as that any, so evil-disposed, should hardly attain to counterfeit the same'; the coins were to have limited legal tender and privately issued tokens were forbidden. But the proclamation was never issued.[70] Instead, a city like Bristol obtained official permission to issue square lead tokens the following year.

[69] Details in Peck (1960, 19–49).
[70] Peck (1960, 9–10, 581–2).

From the period from 1644 to 1672, over 12,700 different types of tokens have been catalogued, issued in 1,700 different English towns. Suppliers were either city councils, owners of firms, local retailers. Tokens usually bore the name of the issuer, and convertibility was implied or explicitly promised. One of the better documented issuers was the city of Bristol. It obtained permission to issue copper farthings in 1652, and made further issues in 1660 and 1669 (Thomson 1988, vii–xxxiii). By a city ordnance of June 1652, the Mayor and magistrates "to the end also that no person or persons shall or may suffer any loss or prejudice by them, have published and declared that they will from time to time receive and take them in and allow them after the rate of penny for 4 of them, and so after that rate for any quantity whatsoever, if at any time hereafter they shall be refused to pass within the said city, or any obstruction be in the utterance of them."

The Slingsby Doctrine Throughout the period of the Commonwealth, projects were put forward to replace these private tokens with government issues. One such project was made by Sir Henry Slingsby (1621–90), who was to be master-worker of the London Mint from 1662 to 1680, and at the time a prime mover behind the ongoing mechanization of the minting process (Mayhew 1992b, 343).

In a memorandum to King Charles II, dated June 5, 1661, Sir Henry Slingsby proposed to mint farthings ($^1/_4$d, the smallest existing silver coin being 1d).[71] He made what may be the earliest statement of Cipolla's standard recipe, when he wrote: "Copper is the fittest metal; a contract should be made with Sweden for the supply thereof, and it should be coined at so little increase of price as to make counterfeiting disadvantageous. To avoid a danger of glut, the Mint should be always ready to exchange farthings for silver money, if requested, and should forbear to make more than demanded."

But theory was still ahead of technology. As the Castilian experience demonstrated, governments' cost advantage over their competitors were insuffi-

[71] The text is quoted in Boyne (1889, xlii).

cient, in spite of the new minting process.[72] The government of England, like those of most other countries, held back from token coinage for another 150 years.

Government Monopoly Instead, soon after implementing mechanization in 1660, the royal government decided to mint its own copper farthings and half-pence, for the first time. The proclamation of August 1672 asserted that "our subjects would not easily be wrought upon to accept the farthings and half-pence of these private stampers, if there were not some kind of necessity for such small coins to be made for public use, which cannot well be done in silver, nor safely in any other metal, unless the intrinsic value of the coin be equal, or near to that value for which it is made current." The mint was ordered to make half-pence and farthings "to contain as much copper in weight as shall be of the true intrinsic value and worth of a half-penny and a farthing respectively, the charges of coining and uttering being only deducted." The new coins were made legal tender for payments up to 6d. Slingsby was put in charge of the copper coinage, and contracted with a Swedish merchant to purchase copper. The face value of a pound of copper was 22d, the cost of the copper was 14$\frac{1}{2}$d and expenses were 4d (Craig 1953, 175); net seigniorage was thus 16%. The coins were widely counterfeited, and the minting stopped in 1676, after about 40,000 had been minted.

The English government kept looking for ways to avoid counterfeiting, by adding reeded edges to coins, or by using plugs of a different metal inside the coin, or looking for better alloys. Tin was experimented with between 1684 and 1694, although more as a means of subsidizing Cornish producers at a time of decline in the price of tin. the net seigniorage rate was 40%; to defeat counterfeiters, the coins had a copper plug and the edge was inscribed (Peck 1960, 107–8, 151–2). In spite of those measures, the House of Commons found those coins wanting in value and too easily counterfeited, and ended their production in 1694, over the protests of the Cornish mines.

[72] The Bristol farthings, at a face value of 32d to 40d per pound of copper, are known to have been counterfeited.

The lack of success in finding measures against counterfeiting explains English monetary officials' attachment to full-bodied copper coinage. The copper coinage of 1694-1701 was issued at 21d per lb, even closer to intrinsic value than in 1672. When the government decided to resume copper coinage in 1717–18, Sir Isaac Newton insisted that it be minted at intrinsic value plus costs.[73] Small quantities of copper coins were issued in the 18th century (1717–24, 1729–55, 1770–5), and little was done to repress private imitations of the official coinage.

This absence of repression soon led to another Free Token Era. "By the 1740s competition had driven the copper in private coins of mixed metal down to one-eighth of that in legal coin" (Craig, 253). In 1754, official coinage was stopped on a petition from London retailers complaining that copper had overtaken gold and silver in retail coinage. Counterfeits, which had appeared after 1725, became numerous after 1740. In 1751, the first 'evasions' appeared: those coins imitated the general appearance of the official coinage but was clearly differentiated. Counterfeiters sold them at half-price to wholesalers, who resold them at 28s to 30s for a gold guinea of 21s. Not being exact copies, they were not counterfeits and the government tolerated them. By 1753, 40 to 50% of the stock of copper in circulation was counterfeit, and by 1787, the mint estimated that only 8% of copper coins in circulation "had some tolerable resemblance to the king's coin."[74]

Then, after James Watt first harnessed the steam engine to a minting press in 1787, trade tokens issued by firms and employers became extremely common: convertible tokens once again emerged as the predominant form of small change in England. Most of the trade tokens were made by Birmingham firms, were of the same weight as the official coinage, and carried the issuer's name for redemption.

[73] "Halfpence and farthings (like other money) should be made of a metal whose price among Merchants is known, and should be coined as near as can be to that price, including the charge of coinage . . . All which reasons incline us to prefer a coinage of good copper according to the intrinsic value of the metal" (in Shaw 1896, 164-5).

[74] Peck (1960, 205–15).

The Industrial Revolution and the Advent of the Standard Formula

The last chapter of our tale starts with the decisive shift in the technology which gave governments the needed cost advantage to introduce token coinage. As the earlier chapters make clear, technology was not the only requisite: an understanding of the Standard Formula, and ability as well as willingness to implement it, were needed.

By the 19th century, the problem of small change is not limited to copper or bronze coins, at the lowest end of the denomination scale. Indeed, when England implements the Standard Formula in 1816, it applies it to all of its silver coinage, thus establishing the first full-fledged implementation of the gold standard. Thus, in the 19th century, debate over the Standard Formula was to be a debate between the gold standard and bimetallism. England was not followed by other countries for another 60 years, in spite of the technology's wide availability.

Technology: the Steam Engine

During the 17th century, the only substantive change was the marking of edges of coins with the Castaing machine (invented in England and adopted in France in 1685), a process by which a coin was rolled on a horizontal surface between two steel bars, one of which bore a motto or serrated design in relief.

Several innovations occurred in the late 18th and early 19th century. The portrait lathe and hubbing were invented by the Swiss J-P Droz around 1780: this finally permitted coin dies to be identically reproduced, and eliminated one of the last sources of variation from one coin to the next; it was adopted by Dupré, engraver of the French mint, in 1791.

More importantly, in 1786, Matthew Boulton of Birmingham, partner of James Watt, adapted steam-power to the minting press; by 1810, output

was 70 to 80 coins per minute. Private minters first took advantage of the new technology, the Anglesey Copper Company in 1787 soon being followed by many others. In 1797, the government contracted with Boulton and Watt to produce official copper coins, called cartwheels. But the coins were close to full-bodied, and in the first issue, the penny weighed a full ounce. As the price of copper rose during the Napoleonic wars, the coins were made lighter, to two thirds of an ounce. Royal coinage stopped in 1807, and private coinage continued to be issued until 1817, when they were made illegal by the Act of Suppression. The year before, the government had established its new silver coinage on a token basis, after having installed Boulton's machines at the London mint in 1810.

Matthew Boulton's new technology attracted immediate attention abroad: as early as 1791, the Monneron firm in Paris contracted with him to produce private copper coinage in France; Russia was the first government to buy his presses in 1799, followed later by Denmark and Spain (Craig 264). Steam engines, however, were not easily adapted to the old screw-press, and there were technical problems in accommodating the rotation and recoil of the screw. In 1817, D. Uhlhorn, a German engineer in Grevenbroich near Cologne, invented a lever or knuckle-action press which could more easily be driven by steam. His machine could strike 30 to 60 coins per minute, depending on the size of the coin. By 1840, Uhlhorn had built presses for mints in Düsseldorf, Berlin, Utrecht, Vienna, Munich, Karlsruhe, Schwerin, Stockholm, Wiesbaden and Naples; Uhlhorn machines were also in use in Australia since 1853.[75] The method was adapted by Thonnelier in France in 1834, and the Thonnelier press, striking 40 coins per minute, came in use in Paris in 1845.[76] By the late 19th century, when the Thonnelier press was in use throughout Europe, it could strike 60 to 120 coins per minute.[77]

Redish (1990) discusses in detail the circumstances of the Coinage Act of 1816. It made gold the sole standard of value, and made silver coins representa-

[75] *Meyers Conversationslexicon* (1840).
[76] Blanchet (1890).
[77] *Encyclopaedia Britannica*, 9th ed. The London mint bought its first lever presses in the 1870s, which produced 90 coins per minute.

tive; however, it still allowed for free minting of silver although its legal tender was limited to 2.1. The free minting clause was reserved and never applied. But the Bank of England voluntarily adopted a policy of accepting silver coins at face value in exchange for gold or its notes; only in 1833 was it agreed that it could sell its inventory of silver coins at par value to the Mint, establishing convertibility in fact if not in law.

Bimetallism versus Gold Standard

The policy was only slowly adopted in other countries; moreover, it was initially implemented only with regard to bronze or small-denomination coinage, not to the whole silver coinage as England had done. Thus, bimetallism persisted in the U.S. and much of Europe until the late 1870s.

In the United States, the process of adoption a long and arduous one.[78] The Mint Act of 1792 established a bimetallic system with gold and silver coins freely minted on demand and unlimited legal tender, and full-bodied copper coins minted on government account. The gold discoveries of California and Australia around 1849 pushed the intrinsic value of the silver coinage above its legal tender value and led to its being melted down. Congress wished to remedy the situation without forsaking bimetallism. The result was an Act of 1853 (10 Statutes at Large, 160) which modified the coinage of 5¢, 10¢, 25¢ and 50¢ pieces, making them 6.9% light with respect to the $1 coin and legal tender for private debts for up to $5. They ceased to be freely minted, and the quantities minted were to be regulated by the Secretary of the Treasury. They were sold at par by the mint in exchange for gold coins or silver dollars. Congress, however, made explicit its intention to maintain bimetallism, and clear its rejection of the English model proposed by some. The measures were considered temporary, the diminution in weight was minimal, and there was no mechanism for redemption. Carothers (1930, 126–7) cites concerns about the possibility of private duplication of government-issued underweight coins,

[78] See Carothers (1930).

misunderstanding of and opposition to the principle of token coinage ("There was an almost universal belief that a coin legally rated at a value above its bullion value was a debased coin of doubtful honesty") and fears of over-issue and resulting depreciation.

In 1873, coins of 1¢, 3¢ and 5¢ in copper and nickel were created, with legal tender limited to 25¢. Only by an act of 1879 (21 Statutes at Large 7) was it provided that "the holder of any of the silver coins of the United States of smaller denominations than one dollar, may, on presentation of the same in sums of twenty dollars, or any multiple thereof, at the office of the Treasurer or any assistant Treasurer of the United States, receive therefor lawful money of the United States" (the legal tender limit was also raised to $10).

France's law of Germinal XI (April 1803) had reestablished the bimetallic standard that prevailed before the Revolution. Silver coins were full-bodied, from 0.25F to 5F, and a few bronze coins were occasionally minted at cost (0.05F and 0.10F). In the early 1850s, the gold discoveries of California led to a disappearance of silver in circulation, and the first proposals for token subsidiary coinage were made, and adopted in 1864 for the smallest silver coins (the 0.20F and 0.50F pieces were made 7.2% light). The following year, The 1865 convention creating the Latin Monetary Union between France, Belgium, Switzerland and Italy (and enlarged to Greece in 1868) extended this provision to the 1F and 2F piece, but the 5F silver piece remained full-bodied. The coins were legal tender up to 50F between private parties, up to 100F in payments to any member government, and exchanged by any member government into 5F full-bodied silver pieces or gold pieces in sums greater than 100F. The convention also imposed a per-capita limit on each state's cumulative issue.[79] The 5F piece, however, remained freely minted until the drastic fall of the price of silver in the 1870s led the various member countries to suspend free coinage of silver. France did so by a law of March ??, 1876, whose preamble stated: "The theory of the double standard, on which our monetary law of the year XI reposes, has been

[79] The convention apparently adopted the belt-and-suspenders approach: the coins were close to full-bodied, convertible on demand, limited legal tender, and limited in quantity.

called into question ever since its origin. It is, to our conception, less a theory than the result of the primitive inability of the legislators to combine together the two precvious metals otherwise than by way of an unlimited concurrence—metals, both of which are destined to enter into the montary system, but which recent legislators have learned to co-ordinate by leaving the unlimited function to gold alone and reducing silver to the rôle of divisional money."

Conclusion

Having been discovered by the processes we have described, and being firmly in place by the mid 19th century, two theoretical elements—the quantity theory and the need to to restrain the creators of token money—were in the 20th century to underlie proposals to abandon gold for all denominations, large and small, and to replace it with a well managed fiat money system. In the first half of the 20th century, proposals to install a well managed fiat money were endorsed by leading monetary economists, ranging from Irving Fisher and John Maynard Keynes to Milton Friedman. They called gold a 'barbarous' relic, and argued that armed with the quantity theory and good intentions, a fiat money could be managed to deliver a more stable price level than had been achieved under than under gold. The monetary history of the second half of the twentieth century has witnessed the experiment that these theorists recommended, with remarkable results involving what stands as another (and ongoing) chapter in our tale of social learning. It has taken time and experience for managers of fiat currencies to learn how to deliver the performance that Irving Fisher and the others promised us. Mainly, they have had to learn how to combat the two great enemies of price stability in a fiat money system: the pressure to supply to the Treasury revenues from an 'inflation tax'; and belief in some form of exploitable Phillips curve. In the last two decades, inflation has fallen dramatically in one country after another as authorities have learned how to manage the system.

The picture of 'social learning' that emerges from our story mixes technological change, imperfect theorizing about data, and intermittent new 'exper-

iments' delivered by decision makers who were more or less influenced by preeminent existing theories, followed by more theorizing to make sense of those experiments. This process partly resembles vision of David Kreps, who views time series data as emerging recursively from an adaptive joint estimation-decision making process, where parameter values of a statistical model to be used for decision making are recurrently updated as new data appears. The history of token coins reveals something that is hard to capture in Kreps's type of model, namely the leaps of intuition or 'paradigm shifts' that punctuate the learning process. The discovery of the quantity theory and the growing understanding of alternative mechanisms for restraining creators of money exhibit features of insight and foresight that are hard to instill into the adaptive agents in Kreps's models.

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