Satoshi’s Engine

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Everything you need to know about proof-of-work mining economics and dynamics

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FOREWORD

Before You Start

What this book assumes, what it leaves out, and who it is for

This book explains a machine inside a machine. Not a specific network, not an investment, not a movement. A machine, in the ordinary sense of a thing with parts that push against each other and produce an output.

A proof-of-work network is a large machine and this book is about its engine. The rest of the machine routes, verifies, orders, secures and records: it moves things that already exist. The engine is the part that converts. Energy goes in and a coin comes out with a cost behind it, and everything the network does afterward is done with that output. Most writing describes the weather around that engine rather than the mechanism underneath.

What makes the conversion strange is what sits on either side of it. The coins are finite. How many exist and how fast they arrive are fixed by rules nobody can amend under pressure. The effort to obtain them is not finite at all. The protocol can write one of those two sides and not the other: it defines the prize, and has no power whatever over what competing for it costs. Nothing caps how many machines can be built, how much capital can enter, how good the engineering gets, or how hard people will compete for a quantity that was already scheduled before any of them arrived.

So the engine sits between a bounded thing and an unbounded appetite for it. When the coins become more valuable the unbounded side answers, and it does: more machines, better machines, more capital, cheaper power. What it cannot do is produce more coins. That constraint is the whole subject of this book.

Mining spends two things. Energy, which is the part everyone counts, and time, which is the part that decides what the energy was worth. Most of what follows is one being traded for the other.

It assumes almost nothing. If you know that mining involves computers using electricity to earn coins, why working harder yields more coins to you and no more coins overall, and roughly how supply and demand set a price, you know enough to start. Everything past that gets built here, in order, and any term that carries weight is defined the first time it appears.

The Shape of It

Part One tells the story with no numbers at all. One full turn of the cycle and half of a second, one phase to a chapter, from the moment a price first exists to the second time the market falls still. Reading it should leave you able to recognise which part of the cycle you are looking at and say why it is there.

Part Two puts units on the same story. What a machine spends, what a coin costs, why buying hardware and running it are the same expense on two schedules, and why waiting is charged whether or not anybody bought it.

Part Three adds the piece the first two leave out. Fees. A second way miners get paid, minor while the subsidy lasts and eventually the only one, kept deliberately brief because the subject runs much further than this book needs it to and resolves back into the cycle anyway.

The closing chapters test the book's own title against everything built before them, trace both halves back to the thought experiments they came from, and say plainly what is still unsettled.

What Is Deliberately Missing

No network is named anywhere in these pages. No machine model, no dates, no prices. The mechanism is identical wherever it runs, and naming examples would date the book and invite arguments about particular projects that have nothing to do with whether the machinery works as described. What does differ between networks is how much of the mechanism leaks away, and this book follows the soundest case, where the least of it does.

The book makes no attempt to catalogue the ways a network can leak value, which is a large subject with a shape of its own. Where that matters, the text says so and points you somewhere it is handled properly.

> *A mechanism is easiest to see where it runs cleanly. Everything here describes a machine with its parts intact.*

Its Companion

This sits beside a longer collection called The Instrument, which works the same territory from the monetary side rather than the mining side. The two overlap at the edges and neither depends on the other. If you want the taxonomy of what makes one network sounder than another, or the fuller treatment of what a coin measures, that is where it lives.

Start here if you want to know how the machine runs. Start there if you want to know what it is measuring.

PART ONE

How a Store of Value Emerges

One phase of the cycle per chapter, a full turn and half of a second, told with no numbers so the shape is clear first

CHAPTER ONE

Hot Machines, No Price

Before there was a market, there was only heat. Then, one day, the heat met a price, and something began that had never existed before

HOT COINS, HOT ASICS · THE CYCLE BEGINS

Every fair-launched proof-of-work network begins the same way. Nothing pre-allocated, nothing promised in advance, just software released into the wild.

At the start, a machine runs and nothing is pricing it or what it produces. An ordinary computer, doing ordinary work, solving a puzzle that yields a coin nobody outside a small circle has tried to buy. No market. No number to check the effort against. Whoever runs that machine runs it on belief, and the belief has a definite shape: this thing is a tradable commodity, and a tradable commodity can eventually be exchanged for goods, services, or another currency. There is nothing available yet to confirm or refute it.

From CPU to ASIC, Before Anyone Was Watching

The hardware tells the story by itself. Mining began on ordinary processors, the same chips already sitting in everybody's desktop, handling this work as one task among many. As word spread, graphics cards took over. Built for rendering images, they turned out to suit the repetitive number-crunching mining demands.

Then came a stranger intermediate step: field-programmable chips, hardware reconfigured for the task rather than built for it. After that, the

final form. Application-specific integrated circuits, silicon designed for one purpose and incapable of any other.

The two steps are unalike, and the difference explains the pacing. Moving from a processor to a graphics card costs nothing but software. The hardware was already bought, sitting in the machine, doing something else. Anyone could switch over on an afternoon and switch back just as easily. Field-programmable chips and purpose-built silicon are a different proposition entirely: money committed upfront against a return nobody has promised, on hardware that will never do anything else if the bet is wrong.

So the progression waited. Nobody commits capital to building a machine that can only mine until mining visibly pays, and nobody could see whether it paid until there was a price to check against. The early steps happened because they were free. The expensive ones happened later, for the reason expensive things always happen, which is that somebody could finally measure the profit.

Each step pushed the same trade further. Surrender flexibility, gain efficiency. No market rewarded this. It happened because the people running these machines expected the coin to justify the effort someday, and kept spending on that expectation alone.

> *The machines were hot long before anyone outside a small circle knew they existed. Heat came first. Price had not been invented yet.*

When the Outside Arrives

At some specific moment, that changes. Someone offers to buy the coin. Someone else agrees to sell it. A price exists where none did before.

Two beginnings get conflated when people speak of a network's genesis, and only one of them is the one everybody names. Genesis is block one: a network launched, energy spent, coins produced that nobody has valued. It has a height and a timestamp and an announcement, and from that moment a network exists where none did. That is the whole of what it

changes. None of the machinery in this book starts turning, because every part of it stays dormant until something on the other side appears.

The second beginning works the other way round. Nothing originates in the network this time. Something arrives from outside it, when people who were never part of the machinery decide they want what it produces. There is no block height for that and nobody schedules it. It turns a smouldering into a fire, and the important part of the image is where the air comes from: the heat was already there, produced by machines that had been running for months, and what arrives is not the spark.

The engine needs this to be true. A heat engine runs on the distance between two reservoirs, and until a price exists there is only one of them, cost of production with nothing on the far side. No distance, no work. Price is not the engine starting. It is the second reservoir appearing.

It also happens once, which makes it the first irreversible step in the whole story, arriving before any ratchet and before anything begins to accumulate. A price that exists does not go back to never having existed, not at a bottom where almost nothing trades and not afterward.

Everything that follows starts here, because two things that had sat apart finally touch. On one side, physical mining effort, already running, already burning money, indifferent to whether anyone outside noticed. On the other, a price arriving from strangers who have no idea what the mining costs, valuing the coin purely on what they guess its scarcity is worth.

From that moment the two do not simply sit beside each other. The instant they connect, the connection stops sitting still. It begins pulling on itself.

Coming In Hot

That first price arrives hot rather than gently. A market discovering a scarce thing, with no information about what producing it costs, almost certainly overshoots. Price lands above the physical cost of production, not below it and not level with it.

That distance has a name this book returns to constantly. The profitability gap is price minus cost: what a market will pay set against what a

machine spends earning the payment. Here, at the beginning, it opens for the first time and opens wide.

Better to picture it as a distance than a subtraction. Two lines, price and the cost of making a coin, and the gap is the space between them. Price moves first and moves on opinion, so it can go anywhere. Cost follows, dragged along by the machines that arrive because the space looked worth entering. Widest separation is peak profitability. When the two finally meet there is nothing left to extract, and that meeting is what a bottom is.

What the Gap Does First

A wide profitability gap does not sit quietly. It moves people.

The most direct way to act on it is also the most literal: sell coins already sitting in a wallet, buy machines, mine more coins. That move recurs constantly from here on. Coins shift out of reserve and into circulation. Not a crisis, just what people do once they notice the coin in hand is worth more than the cost of producing another.

This moment has a name: hot coins, hot ASICs, machines being what ASICs are. The shorthand needs a short explanation. Coins and ASICs get tracked separately, because the market has two eyes and watches both, always asking which is the better trade right now. Each is either hot or cold, and the words carry a specific meaning. Hot means demand running ahead of what holders will part with, which is scarcity in the only sense a market registers. Cold means the reverse, liquid supply exceeding what anyone wants at the price, which is abundance.

Which gives a test anyone can apply without knowing anything else. Price rising means coins are hot; price falling means holders have put more on the market than it will swallow, which is cold. Hashrate rising means machines are hot; hashrate falling means more were built than the network needed at the time, which is cold. Two directions, and between them they tell you which phase you are standing in. They do not always move together, which is the point of tracking them apart.

Here both run hot at once. Price has just met a cost that already existed, and the machines generating that cost were already doing the work, waiting.

CHAPTER TWO

Everyone Saw the Same Opportunity

A gap that obvious keeps no secrets, and closes fast once everyone spots it together

COLD COINS, HOT ASICS · THE FIRST TURN

A wide gap sits between price and cost, and coins are flowing out of reserve into circulation as holders spend that gap on the machines that will later close it. Such a discovery stays private for about as long as it takes somebody else to reach the same conclusion.

Once profit becomes visible, more than one manufacturer notices, and more than one decides to build machines into it.

The Coin Turns First

Watch the coin before the hardware, because that is the order things happen in. Every eye is on mining now and the coin barely gets a glance, but demand for the coin is what pulled demand for extracting it, and it is the coin that turns first. Those coins holders sold to fund machines did not disappear. They went to market, becoming liquidity, and they kept going, joined by everyone else doing the same math at the same time. Liquid supply arriving faster than anybody demanded it is abundance, and abundance has one effect on price.

So price stalls, then turns, or overshoots badly and breaks, and it does this while the gap that started everything still looks open on paper. Every miner sees the profit a machine would earn arriving today. They all arrive tomorrow, and what will close the gap is still being built.

The Flywheel

Nothing on the mining side has noticed yet, and it will not for some time. To see why, picture the network as a flywheel, because that is close to what it is.

Demand from the coin market pushes on it as price rises, and liquid supply coming the other way relieves the push. Not steadily and not gently, but continuously, and never quite down to nothing. Even in the deadest market some force is still arriving at the rim. What varies is how much.

Against that push sits friction, which is the cost of keeping machines running. When the push exceeds the friction, the wheel accelerates and hashrate climbs. When it falls below, the wheel slows. It does not stop. A flywheel with a weakening drive keeps turning on what it already has, and what this one already has is machines bought, contracts signed, and orders placed months ago against a gap that looked permanent at the time.

> *The drive never switches off. It drops below what the wheel costs to keep spinning, and the wheel spends a season finding out where the push will be matched again.*

So the two markets can point opposite ways for months without either one being wrong. Price fell because the push weakened. Hashrate rose because the wheel was still carrying everything the last push put into it, the working capital committed to orders and the lag between production and arrival, and more was still being added by machines already in production. Both are the same flywheel, read at different moments of the same stroke.

Everyone Builds the Same Thing

Nobody can keep a wide, visible margin to themselves, and the pattern repeats throughout this book. Every manufacturer capable of building

competitive hardware sees the same number the first one saw, and faces the same incentive.

So they build, at roughly the same time. Several manufacturers, several designs, all racing hardware to market while the gap stays wide enough to justify the effort. They do not collude. None of them need to. They read the same signal and reach the same conclusion separately. Call it forced convergence: independent actors, uncoordinated, landing on the same number because one shared cost binds every one of them.

The Party Ends

A miner recognizes this moment by feel. The machines land all at once, from every direction. Hashrate does not creep. It spikes, as units from every competing manufacturer come online inside the same few weeks.

It closes from both directions at once. Price has been falling for months. Now the hardware ordered against the old, wider gap finishes production and reaches the floor, landing into a market that has already turned. Difficulty climbs to match. A miner is squeezed from above and below in the same season: fewer dollars per coin, and a smaller share of the coins.

> *The machines were already ordered. Already plugged in. You cannot un-mine.*

Profit does not taper here. It collapses. Neither half alone would do it. Together they take the margin out in a matter of weeks.

The weakest machines start going off. The ones with the worst power contracts cannot cover the bill at these numbers and stop, months after the coin first told everyone what was coming. They are not yet enough to matter. More are still arriving than leaving.

> *Nobody closes the gap on purpose. It closes because everyone who could see it moved at once.*

Capex Starts to Fall

Hardware prices turn the moment the margin does, which is earlier than almost anyone notices, and they do not stop. A machine is worth what it can earn, so the instant hashrate starts outrunning price the thing being sold is worth less than it was last week. Manufacturers who built for the wide-margin moment are holding inventory against a margin that has already gone, and unsold stock in a shrinking market becomes a liability by the week.

They are not the only sellers any more. The weakest miners, the ones whose power costs left them no room, are already giving up and putting machines on the market rather than run them at a loss. Barely any used hardware existed before this. Now some exists, and it is priced by people who need it gone rather than by people who need to cover a production cost.

Which is why capex falls faster than profitability does. A shrinking margin would lower machine prices on its own, slowly, as buyers did the sums. What actually happens is that manufacturers find themselves bidding against sellers with no production cost to recover, and the price of a new machine has to move faster than the thing it is priced against.

None of this stops the hashrate climbing. Machines ordered months ago are still landing, and they land faster than the quitters leave. So the network is still gaining speed while everything underneath it has already turned, and the top is still ahead.

Two Markets, Out of Step

A chapter that opened with everyone rushing the same opportunity closes with the rush dismantling itself. Hashrate climbed hard, difficulty answered, and the profit went out the window while machines were still arriving from factories that had taken the order months earlier.

The coin is not waiting its turn. It went first, months ago, and has been falling the whole time the hardware was still arriving. Holders who bought near the top were selling into weakness while manufacturers were

still shipping against a gap that had already closed, and the largest of them were out early, because a large position cannot be unwound quietly and waiting makes it worse.

So there are two markets falling out of step rather than one falling after the other. The coin started down and kept going. Hardware kept arriving on orders placed against conditions that no longer existed, and its price was already falling while it shipped. What has not happened yet is the top. Hashrate is still climbing, because arrivals still outrun departures, and it will keep climbing until they do not.

CHAPTER THREE (A)

The View Half Way Down

The used market takes the sale, then runs out of machines to sell, and the market for hardware dies before the mining does

Stop half way down and look at what has become visible. The coin has been falling for months and is still falling. Hashrate has passed its peak and started back. And the market for machines, which was the loudest thing in the story a moment ago, is about to go silent faster than either of them.

The Used Market Wins

The used market works like a heat sink. It does not stop heat from being generated. It gives the excess somewhere to go, soaking up the machines, the capital, and the urgency a hot market throws off, so everything else can cool toward something stable instead of cooking indefinitely.

A manufacturer selling new must cover production cost. A miner selling used need not. They are salvaging whatever value remains in a machine that has stopped earning its keep, and will take a steep discount to be rid of it.

So the used market undercuts new pricing, and once it does, it wins the sale outright. Given a new machine at the manufacturer's floor and a near-identical used one below it, few buyers pay the premium. New sales slow. Used sales accelerate. The manufacturer who started all this by

building into an open gap now watches the wreckage of that same cycle outcompete the product.

> *There is no free will here, only game theory. You follow the rules, or you go bankrupt.*

Nineteenth-century railroads fit this better than a gold rush does. A gold rush ends with the gold gone and the shovels worthless, dead capital with nothing left to do. That is not what happens here. Railroads tell the truer version. Fortunes went into laying track during a genuine mania, most of the builders went bankrupt, and the track stayed, carrying trains long after the money that funded it had vanished. These machines do likewise. The capital gets wiped out. What survives is not scrap but infrastructure, the substrate everything later in this book runs on, still producing blocks regardless of who lost their shirt building it.

The Used Market Runs Out of Reasons to Move

A used market that keeps winning eventually exhausts what let it win. Machines dumped once by capitulating owners rarely get dumped twice at the same price. New units, pinned at the manufacturer's floor, stopped attracting buyers a while back and largely stopped arriving. The hardware side settles into a standstill. Survivors keep running, keep mining, and stop changing hands. Nobody selling has inventory left. Nobody buying has cause to bid above the price already sitting there.

Hardware prices settle at whatever it costs the last surviving miners to produce. Nobody declared that figure. No other figure remains available.

Two Kinds of Compression

The gap that started all of this, between what a coin fetches and what it costs to make, has run out of room. Price sits at what it costs the marginal

miner to produce a coin, and there is nothing left between them to extract. It peaked far back in the climb and has been shutting ever since.

The joules it takes to produce a coin are set: a given machine, a given difficulty, a given amount of work behind each coin. Turn that into money at the marginal miner's electricity rate and you have a number. Any price above it and that miner sells at a profit. As price falls toward that number the margin thins, and the miner covers the same bill by selling a larger fraction of what she mines. That is what stops the fall, and it stops it for a reason more definite than price respecting cost. The fraction has a ceiling. Nobody can sell more than a hundred percent of what they produce, so at the bottom the selling pressure the market can generate is capped by issuance itself and cannot be pushed further. Below that the adjustment has to come from somewhere else, which means machines going off.

What compressed on the way down was the price of hardware, not the physics inside it. The machine is the same machine. It draws what it drew and does what it did, and only what anyone will pay for it has moved.

Buyers of a popular machine near a peak paid prices weighted heavily toward capex, on a payback timeline that assumed elevated revenue would hold. It did not hold, and payback stretched far past what the purchase assumed. The same machine bought near the following bottom, at a fraction of that price, carried a far smaller capex share. Its efficiency was identical at both prices. Only what the market would pay for it moved, and it moved enormously, while the physical number underneath held still.

That unchanging physical number has a name, and this is the place to pin it down, since the term appears constantly from here on. The joule limit is the energy a machine spends to do one unit of work. It is approached and never arrived at, and the closer the approach the smaller each remaining step becomes.

Which machine? Not the weakest one still hanging on, and not necessarily the best one in existence, though it can be. The one that beats every rival

on total cost, purchase price and running cost together. Capital swarms whichever machine wins that comparison, so it ends up doing most of the work on the network. In this book that machine is the workhorse.

Nothing about vintage decides it. The workhorse is often not the newest thing available. A machine two generations old, bought cheap and already paid for, can beat a better one still carrying its purchase price, and it holds the position until something wins the comparison outright. Total cost decides, and total cost includes what the thing cost to acquire.

The limit is one number. Joules per coin is another, and the difference matters for the rest of the book. The limit is what a machine spends to do a unit of work. Joules per coin is what it spends to win a coin, which depends on its share of everything else running, because a coin does not go to whoever burns the most energy. It goes to whoever did the most work while everyone else was also working.

So a better machine takes a larger slice of the same issuance for the same power, and its energy per coin is lower than its neighbour's. A worse one is higher. There is no single figure for the network, since the network is a mixture of hardware of every age, and nobody can weigh that mixture exactly. The workhorse is the closest thing to an answer, being what most of the work is actually running on.

The two point opposite ways. The limit only ever steps down, because better silicon keeps arriving, though no individual machine improves. What a given machine cost to run the day it was switched on is what it costs today. What moves is which machine the limit sits on.

Joules per coin goes the other way, and it moves for a reason outside the machine entirely: how much total work the network demands for each coin it releases. That rises when a gap pulls in more capacity than it displaces, and rises again when issuance thins the same effort across fewer coins. A miner arriving into a market with no gap changes little, since he mostly pushes the weakest one out and the balance holds. It is the gap that moves the number, not the arrival.

Here two mechanisms hand off. Fast, reversible, competitive compression, the same machine getting cheaper as rivals bid its price down, is the local story this book has told from the beginning. Slow compression, where the limit steps onto a better machine, has not happened yet.

It also does not happen on its own. Better hardware can exist for a long stretch and move nothing, because a cheap secondhand machine is a hard thing to beat on total cost. The miners with the cheapest power buy the newer one first, since at their rate the sums already work, but they are too few to shift what most of the network runs. The limit waits, then drops in one motion when the challenger wins the comparison outright.

The wrong lesson is easy to take from that step. A better machine lowers what a machine spends per unit of work. It does not lower what the average coin costs to produce, and usually does the opposite, because the machine that lowered the figure also attracted the competitors who raise it. Watch the two separately from here on. The energy behind one unit of work falls. The energy behind one coin climbs.

CHAPTER THREE (B)

The Rest of the Fall

Hardware has stopped trading. The coin has not stopped falling

COLD COINS, COLD ASICS · THE FIRST BOTTOM

Stillness is not the end of anything. It is where scarcity gets settled, and it settles at a number nobody chose.

Why the Fall Is Loud Before It Goes Quiet

Stillness at the bottom does not arrive gently. It is the exhausted endpoint of something loud, and the loud part explains why the quiet holds once it comes.

Early in a fall, with volume still moving and buyers still willing to take the other side lower, a prisoner's dilemma runs. Nobody wants to be the last holder in a position that keeps getting cheaper. Selling now at a loss beats selling later at a bigger one, and everyone reasoning that way at once is what drives price down. Each buyer steps in below the last, not from misjudgment, but because that is the coin's worth to somebody willing to catch a falling knife.

It continues as long as volume permits. While willing sellers and willing buyers keep meeting at lower and lower prices, the fall keeps moving. It halts when that volume dries up, when nobody remains willing to sell into further weakness and nobody remains willing to catch it. Not a change of heart. A market that has almost run out of players. Only the forced sellers are left, still selling most of what they earn to stay afloat, because the power bill does not care how thin the bidding has become. It never goes

to nobody. A network where nobody at all will buy is a network that has stopped, and there would be no bottom to describe.

Why the Quiet Holds

The coin reaches its own stillness by a related but separate route, and it arrives last despite having started first, still falling long after the hardware market stopped trading. Coins do not vanish when price falls, and somebody owns every one of them at every moment. What changes is willingness to move.

A trader and a miner both chase a gap, but one chases a soft cost, whatever the coin was bought for, and the other a hard one, the physical expense of running a machine, fixed by physics regardless of anyone's opinion. That difference decides who can wait. A trader facing a thin, unfavorable market can do nothing. A miner has no such option, because the electricity bill arrives whether or not the market is watching, so a miner still producing at a margin keeps selling at whatever price exists, as long as covering that bill beats failing to cover it.

Which sets a limit on how quiet the coin can go. It can go very quiet, and does. It cannot go silent, because a miner who cannot sell cannot pay for power, and a network whose miners cannot pay for power does not continue. Whatever else is true at a bottom, somebody is still buying, or there would be no bottom to describe.

That holds in the other direction too. Whatever miners have to sell has to be absorbed by a market larger than their selling, or the selling has nowhere to go. The coin market is necessarily the bigger of the two, not by preference or by stage of adoption, but because the alternative is a network that has already stopped.

A holder underwater has little reason to sell into a thinning market, since selling locks in a loss that might evaporate in six months. A holder slightly ahead has little reason either, since a thin market cannot absorb the sale without moving price against them. Both reach the same conclusion from opposite directions. Hold.

A second reason sits underneath the thin market, and it has less to do with how people reason than with who is holding what. Where the losses sit answers it. A lot of them belong to people who bought near the top, because that is when volume was high, and volume is high when price is. They are underwater on a purchase made at a price this market has not seen in a long time, and nothing available at the bottom interests them.

Then look at who is still in profit. Not recent buyers. People who bought or mined very early in this cycle, back when almost nobody was, which means they already watched a top arrive and chose not to sell into it. Whatever that top offered was not enough for them then. Something lower is not going to be enough now. They are not waiting for a better price so much as waiting for a better top, and one with more volume behind it than the last.

Where the Two Vectors Cross

A bottom has a structural definition, and this is it. Market supply, meaning coins somebody will actually sell right now, keeps shrinking as holding rises. Demand need not grow at all for something to happen. It only needs to hold still, or stop shrinking faster than supply does.

At some point they cross. Remaining demand exceeds remaining willing supply, and two kinds of scarcity meet here that collapsing into one word would confuse.

Structural scarcity is supply that stays limited however much work or capital is thrown at it. A miner can take a larger share by outworking everyone else, and everyone else takes less by that much, and the total does not move. A hard-capped coin has this from block one and never loses it, because no quantity of effort makes issuance arrive faster than the schedule allows. It is not a condition a market can enter or leave.

Active scarcity is the live condition: demand exceeding what holders will part with at the price on offer. That begins here, at the crossing, and it ends when price rises far enough to pull supply back out. A coin sits in structural scarcity its whole life while the active condition swings from abundance to shortage and back again, which is what the cycle is.

The scarcity was always there. It only ever needed pressure.

Seen from far enough back, both halves of the cycle are hunting that crossing, and they hunt it from opposite sides. On the way up the market looks for the point where supply finally outgrows demand, bidding until enough holders decide they have had enough and step in front of it. On the way down the market looks for the point where demand crosses back, testing the least anybody will accept, taking the path of least resistance the way water does.

Structurally the two searches are identical. Their targets are not. What holds the lower crossing in place is what a machine costs to run, which is physics and does not negotiate. What holds the upper one is a distribution of cost bases and expectations among holders, which is a wall made of opinion. Both crossings are real. Only one is anchored to anything.

Most things do not work this way, which is what makes the distinction earn its keep. Raise the price of an ordinary manufactured good and producers make more of it, so the shortage calls into being the supply that ends it. Raise the price of gold and the answer still comes, only slowly and weakly, because a deposit has to be found and a mine has to be dug. Here the pressure has nowhere to go at all. Nothing new can flood the market, so only what has been mined and held can, and only when price offers enough to pull it out. In an ordinary good new supply ends the scarcity. Here old supply has to do it.

Not Declared, Produced

Searching and negotiating is how the market gets there, hour by hour, and none of it decides where the searching stops. Three things fix that between them. What the workhorse spends per unit of work, what its electricity costs, and how much work the network demands for each coin it releases. Multiply the three and the number is there before anybody goes looking for it. The market finds that spot rather than choosing it, because the seller waiting at the bottom is a forced one, and a forced seller stops only where stopping costs less than continuing.

The third looks like the one that should wander, and through a long descent it barely does. Hashrate falls, but issuance is falling too, and the two declines run close enough together that the work behind a coin holds roughly where it was. A machine that needed a certain number of joules per coin at the top needs about the same number a year into the fall.

That is not luck, it is what pins them. Let hashrate fall faster than issuance and the work behind a coin drops, costs drop with it, mining turns profitable again and machines stop leaving. Let hashrate fall slower and costs climb above what price can support, and more capacity switches off until it does not. Either way the two declines get lashed together, and the cost of a coin sits still while everything visible is moving.

This is the flywheel finding its speed. The push weakened until it matched what friction takes, and the wheel settled there rather than stopping. Machines still turn, coins still get produced, and the whole thing runs at the pace a shrinking drive can sustain.

> *Through the whole descent the number barely moves. What moves is the price, coming down to meet it.*

Which is why the floor behaves like a shelf rather than a slope. It does not drift down as conditions worsen. It holds at whatever the workhorse and the network's average power rate make it, and then steps, in one motion, when the majority switches to the only thing that can undercut those who have not. While market price sits above that shelf, freshly minted coins arrive as forced sellers, undercutting the market whether their owners like it or not, and the pressure continues until demand outgrows what the selling can absorb or price finishes the trip down.

Two Stillnesses, One Bottom

The bottom is not one event but two stillnesses landing near each other. Hardware stops moving because both sides ran out of reasons to trade.

Coins stop moving because both sides reached identical conclusions from opposite directions. Underneath, supply and demand finally cross for the first time since the mania started.

This is the hinge the whole book turns on, and it deserves marking rather than passing as another chapter. Everything up to here has been local: machines, manufacturers, a used market, one cycle spinning through its phases. What comes next is not. The floor this bottom leaves behind does not reset for the next cycle to spin around. When it moves it moves one way, and it never moves back. This is the point at which it ratchets.

CHAPTER FOUR

A Little Demand Goes a Long Way

At the bottom, holding was the only rational choice. Now it starts to matter that almost everyone made the same one

Both markets are still, for the same reason. Nobody on either side gained anything by moving. Balance like that does not last, and tipping it takes almost nothing.

A Thin Market Moves Easily

At the bottom, willing supply had shrunk to almost nothing, since nearly every holder had reached the same verdict. Selling here gains you nothing.

A market this thin needs little demand to move. Slightly more buying than the trickle of selling still happening, and price rises. The change is not dramatic. Almost nothing stands in the way.

Holding Was Already the Default

Nobody adopted holding as a strategy in response to rising price. It was the rational default at the bottom, before any of this began, arrived at

from both directions at once and for reasons unconnected to expecting recovery.

So price begins rising against a population already positioned to hold. Price enjoys an advantage here it will not have again later in the cycle. Almost nobody waits to sell into the first sign of strength, because almost everybody arrived committed to waiting.

Not that these holders are patient. The ones underwater bought near a top and are nowhere near it. The ones in profit passed on that same top when it was in front of them. A recovery from the bottom does not reach either group. It would take a price above the last peak, on volume to match, before the second group even starts thinking about it.

> *The stillness that made the bottom quiet is what makes the recovery outrun the fall.*

The Miners Stop Selling So Much

Something else shifts as price lifts off the floor, and it works against the market finding a ceiling. At the bottom, a miner at the margin had to sell nearly everything mined, because the electricity bill consumed nearly everything a coin was worth. Lift price and that stops being true. The same bill now takes a smaller share of what the same machine earns, so a smaller share of production has to be sold to cover it. Miners begin keeping some.

In a market already short of sellers, the steadiest source of new supply is the one that cannot stop selling, and it has just started selling less. Holders were already unwilling. Now the one participant with no choice in the matter needs the market less than it did last month. Supply tightens exactly when demand is picking up, and price rises further, which tightens it again.

> *Rising price does not draw sellers out. It excuses the only forced seller from having to be one.*

The loop does not run forever. Somewhere above, price gets high enough that coins bought or mined back when almost nobody wanted them

become worth releasing, and the market floods with old supply that no bill obliged anybody to sell. That is a later chapter. What matters here is that the same mechanism runs in reverse on the way down. Falling price forces miners to sell a larger share to cover the same bill, adding supply precisely when the market can least absorb it, which pushes price down and forces the share higher again. The descent has its own amplifier, and it is the same one.

What This Does to the Hardware Side

The thinness that makes the coin responsive works on the mining side too. At the bottom, used hardware had settled at survival cost with almost nothing changing hands. As price climbs, even slight improvement in profitability makes the idle machines left over from the bottom worth switching back on.

No new hardware need arrive. The infrastructure never left. It kept mining while the market around it went silent. What changes is how much of it justifies running at the current price, and that number climbs the moment price does.

Nothing was destroyed when hashrate fell. Machines were switched off and put somewhere, and there they sit, track already laid and paid for, carrying no traffic. That is why the climb back can be so fast. Capacity does not have to be built, only switched back on, and the only question anybody asks is whether the current price justifies the power bill.

The climb out starts quietly and starts easily, because almost nothing remains in its way. A little demand moves a thin market. A population committed to holding does not interrupt it. Idle machines earn their keep again without anybody building anything.

Quiet does not last.

CHAPTER FIVE (A)

Mining Is Fun Again

The machines that get built now cost more than the ones they replace, and everyone paying that price knows exactly why

HOT COINS, HOT ASICS · THE SECOND TURN

Price is rising against a thin market and idle machines are switching back on as profitability returns. What follows begins where idle capacity stops being enough.

Old Machines Run Out of Room

The machines still standing were built for a different, lower price. As price climbs, what they earn is worth more. Not more coins, the same coins or fewer as issuance falls, simply coins the market now wants at a higher number. And a hard limit caps how far that goes. The hardware has a fixed physical ceiling on output, however profitable running it becomes.

They are also not the machines that stood here the first time. The ones that came through the bottom are the ones that could survive it, which means the ones that spent least to do the work, and the fleet that emerges is quietly better than the fleet that entered. Nobody chose that. The bottom chose it by removing everything else.

Once enough machines press against that ceiling, capturing more of a widening gap requires new hardware rather than more of the old. New machines arrive here, not because the last generation failed, but because it has done everything it can.

When the Used Market Runs Dry

Before new hardware arrives, the used market does something it has not done since the top. The pool of idle machines has been drawn down all through the climb, and at some point what remains is thin. Demand for used hardware now exceeds what anybody will part with, which is the definition of scarce, and the price of a secondhand machine turns and starts climbing.

That is the signal manufacturers were waiting for, and it explains something that looks wrong at first. New machines arrive priced above the used ones and still take the market, because price is not what buyers are comparing. A newer machine spends less energy per unit of work, so it can cost more upfront and still win on the total, which is the only number that decides anything. The new machine undercuts the old one while costing more to buy.

Built for a Market That Has Already Moved

These machines did not appear on demand. Somebody committed to building them months earlier, and committed against the conditions visible at that moment rather than the ones waiting at the far end of the production line.

Those decisions are not made evenly across the cycle. Deep in the cold, with nobody buying hardware at any price, the case for taping out a new design collapses and the pipeline empties. It refills only once buyers reappear, which means the machines arriving into a recovering market were specified against a market that was still on the floor. Lower price. Higher issuance. Grimmer assumptions throughout.

They land well for that reason. Silicon improves whether or not the market cooperates, so whatever finally ships is more capable than what it replaces, and it arrives into conditions better than the ones it was designed for. A manufacturer holding that combination can ask a premium and get it. The buyer still comes out ahead, measured against running the older machine another season.

> *Nothing was timed. The pipeline emptied when nobody was buying and refilled when they returned, and the lag did the rest.*

One thing moves against the buyer through all of this, quietly and without exception. Issuance only ever trends down. A machine specified when the protocol released coins at one rate arrives when the rate is lower, and spends its working life watching it fall further. A machine tends to earn fewer coins than the conditions of its design implied, and the schedule sees to it that the tendency holds.

The Coin Is Doing Something Too

Hardware carries this phase, but the coin is not idle underneath it. Price is high and still climbing, which means everyone who bought or mined near the bottom is now sitting on a substantial gain and looking at it every day.

Push a little further and something crosses that has no equivalent on the way down. Price passes what the last cohort of buyers paid, then the one before that, until no group of holders is underwater at any price they paid. At the bottom the population splits near evenly between profit and loss, and half of it has no reason to move. Here nobody has that reason to stay still, and the only thing holding a coin is the expectation of a higher number.

Some of them start selling. Not in panic and not all at once, because a rising market absorbs it easily and every sale into strength looks like good timing. That is the beginning of the same abundance that ended the last hot phase, arriving quietly, months before it is large enough to matter. The heat is drawing coins out of storage, and the coins have nowhere to go but the market.

Why the Climb Goes Vertical

Something follows from the empty pipeline that explains the steepest part of the whole cycle, and it is easy to miss because it happens on the hardware side while the effect shows up on the coin side.

Anyone who wants exposure to this thing has two routes. Mine it, or buy it. Mining it means owning a machine, and for a stretch of months there are no machines to own. The last cycle's survivors are already running and their owners are not selling into a rising market. New units are still in production, ordered against conditions that have since improved, and nobody can hurry a fab. So one of the two routes is closed, not by price but by supply.

Everyone arriving during that window takes the other route. They buy the coin, because buying the coin is the only thing available. Demand that would have spread across hardware and coins lands entirely on coins, into a market where holders are already reluctant, and price does what price does when one side of a two-sided choice has been shut.

> *The stretch everyone remembers is the stretch when there was nothing to buy except the coin.*

Which is the direction the causation runs, and it runs one way. Scarce coins make machines valuable, because a machine is a claim on coins. Scarce machines do not make coins valuable in the same sense, but they do force the demand onto the coin, and the price that follows is what eventually funds the machines. Coin scarcity pays for machine scarcity. It is never the reverse.

That window is also where the gap is at its widest, and for the same reason rather than for anything to do with enthusiasm. Price can run as far as opinion will carry it. Cost cannot answer, because answering means machines and there are none to be had. The distance between the two is never greater than in the stretch when the response is physically blocked, and it starts closing the moment the first new hardware lands.

The buyers in that window are purchasing something specific, and it is easy to name wrongly. Price has run above what a coin costs to produce, and the difference buys work that has not happened yet. The coin in their hand carries the joules already spent on it and no more. What justifies the higher number is a larger network, harder to attack, with more

accumulated effort behind each unit, and none of that exists at the moment of the purchase.

So the premium is a debt in a stronger sense than metaphor, and the buying itself calls in the payment. A margin above cost is visible, visible margins pull machines in, and the arriving machines raise the work standing behind every coin until the coin embodies what was paid for it. Nobody collects. The buyer either gets vindicated by a rising cost base or eats the difference, and the miner discharged the obligation by building that cost base higher. It is owed to the arithmetic rather than to a party.

CHAPTER FIVE (B)

Paying Up for a Shorter Wait

The machines have arrived. What they cost is a question about time before it is a question about money

Hardware is available again and everybody wants it at once. What they are willing to pay, and why, is where the good days do their real damage.

A Shorter Payback Is Worth Paying More For

Rising profitability has a mechanical consequence for price, because a machine now pays for itself faster than before. A shortening payback period signals, visibly and calculably, that the machine is underpriced against what it earns.

A manufacturer watching that signal has direct reason to raise price. Not greed. A buyer facing a shorter payback can afford more upfront and still come out ahead. Price rises to meet the opportunity, dragging the payback period back toward whatever buyers will accept.

> *A shorter payback does not stay short. The market prices it back toward the waiting period it always settles near, at a higher cost of entry.*

The buyers are not only careful operators working the numbers. A wide gap pulls in people who want the machine paid off in a season, not across a year, and they are frequently the ones with the worst power contracts and the least room for anything to go wrong. That combination sounds irrational and is not. A short payback is precisely what protects a weak position. Get the capital back before conditions turn and the rest is profit; miss and the machine was never survivable under those conditions anyway.

So the bidding for new hardware is led by the miners who can least afford to be patient. They will pay a steep premium on the purchase price for a credible chance of fast repayment, because speed is worth more to them than price. So capex climbs faster than efficiency alone would justify, and why the machines command what they command during the good stretch.

> *The buyer paying most for a machine is often the one who can least afford to wait for it.*

Capex-Heavy in the Good Days

Paying up like that changes what mining costs during such a stretch. Total cost of producing a coin splits in two: what the machine cost to buy, and what it costs to run over a given stretch. Here the machine price rises while electricity holds roughly steady. The balance tips capex-heavy, with a larger share of total cost sitting in the purchase and a smaller share in the monthly bill.

The balance reverses outright once the cycle turns, capex collapsing toward its floor while electricity resumes dominating.

The Network Breathes Out

A widening gap has a further consequence, and it explains something about the network rather than merely its cost of production.

A miner deciding whether to run a machine watches more than one number. ASIC price, electricity cost, block reward, and difficulty all move, and none move in step, each lagging the others by a different interval.

Wide enough profitability makes that matter less. A broader range of operating conditions turns viable at once. A miner paying more for power, or running older hardware, can profit alongside the most efficient operators alive.

This cuts against the instinct that a hot market rewards whoever is already most efficient. On average it does the opposite, even while the limit stays anchored to the same efficient machine described earlier. The limit holds. The population mining above it widens, diversifies, and grows less efficient on average, because a broader range of conditions can clear it.

> *The best miner does not get worse. The average one does, because the bar dropped low enough for a great many others to clear.*

A wider, more varied population, spread across more power sources and more locations, is a more decentralized network. Mechanical consequence, not coincidence. As the gap closes again, the weakest of that widened population get pushed out first, concentrating hashrate among fewer, better operators. One thing more. The cold that follows does not return to the concentration of the last one, since the limit has stepped down by then onto a better machine. Each cold stretch runs more concentrated than the hot one before it, and less concentrated than the cold before that.

The Cost of Waiting

Something sits apart from the machine price and the electricity it burns. How long the buyer waits before the machine pays for itself, and what can go wrong meanwhile.

A miner buying now, at an elevated price, carries an exposure earlier buyers avoided. If difficulty keeps climbing while payback runs, as more of the same attractive hardware comes online, the return falls short of what the purchase assumed. Paying more upfront for a shorter expected

wait only pays if the wait stays short. Time here is a risk taken on, not a delay tolerated.

CHAPTER SIX

The Rhyme

Notice what repeats. Then notice what does not

New machines arrived expensive and a wider, more varied population of miners spread across the network while the gap stayed open. That cannot run forever. What follows is hashrate catching price and overrunning it, coins turning cold while the machines chasing them still run hot.

Selling to Beat the Competition, Again

Somewhere in this climb, the logic that opened the story returns. Coins get sold to fund machines. Machines get sold to fund a faster exit. The profitability gap, wherever it sits, is visible to everyone simultaneously, and nobody wants to be the miner still deliberating after everyone else has moved.

Those two sales are not the same kind of event, and the difference is between what the cycle gives back and what it keeps. A holder selling at a profit is the market letting off pressure. Price rose far enough to unlock coins that were locked, the coins come out, the pressure drops, and at the next bottom most of them go back into storage. Nothing is left behind.

A miner selling coins to buy a machine is the other thing entirely. That is the gap being converted into hardware, and hardware does not go back into storage. It sits in a shed until it stops paying, and while it sits it adds to the work standing behind every coin the network produces. The first sale is exhaust. The second is what the engine actually extracted, handed over to the part of the mechanism that keeps it.

> *Sell some coins to beat the competition. Which, of course, is exactly what opened this story in the first place.*

What Rhymes, and What Doesn't

Reading this as the same event twice would be a mistake. What changed since the pattern first appeared matters more than what held.

The machines being sold now differ from the first cycle's. Newer, more efficient, bought at a higher price during this particular climb. The population of miners differs too, widened by the climb itself, and due to narrow again as its least efficient members exit first once the gap closes. And the workhorse's energy per unit of work, the limit underneath all of it, has stepped down since the last time this played out, whatever the coin's full joule cost happens to be doing above it.

List what actually differs and the rhyme sharpens. The population selling into this gap is larger than the one that sold into the last, because the wider, more varied field that entered during the climb has not fully thinned yet. The machines they hold were specified during the previous cold stretch, when nobody was buying and the pipeline had emptied, so they were built against grimmer assumptions and arrived into better ones. Issuance is lower than it was, so every one of those machines earns fewer coins per unit of work than its design implied. And the coins being sold are drawn from a shallower pool, because a portion of what went into storage at the last bottom never came back out.

The shape is unchanged by any of it. All of it changes the size. More machines chasing fewer coins, sold by more operators into a market holding less loose supply than last time. The gap closes the way it always closes, but everything doing the closing has grown.

Hence a rhyme rather than a repeat. The shape is recognizable. Nothing inside it is identical.

The Same Gap, Doing the Same Work

A structural reason drives the recurrence, not a quirk of psychology. A wide, visible profitability gap does not survive because people miss it. It dies because they see it, and everyone killing it, selling coins, selling hardware, entering as a new miner, does what killed the last one, though the crowd doing it, and its size, differ every time.

No flaw in the mechanism. That is the mechanism, running again, because the conditions that produced it the first time have returned in a higher but structurally identical form.

Same Shape, New Turn

So the rhyme closes as the first cycle did, coins and machines both sold to capture a gap everyone can see closing. What follows is familiar too. A quiet bottom, both markets going still.

The question this book has built toward is not whether that bottom arrives. It always arrives. The question is where it lands relative to the last one.

CHAPTER SEVEN

A Higher Low

The cycle looks the same from the inside. It is not the same from above

What follows will be familiar. Fast competitive compression, then quiet, both markets going still together. What is worth asking this time is not what happens but where it stops, which means stepping outside the cycle and looking at where it landed.

A bottom is the same condition every time. Miners at the margin covering their power and nothing else, holders split near evenly between profit and loss, hardware trading at whatever the survivors can justify. That state does not improve and never has. What changes between one bottom and the next is the scale of everything that has to arrive there before it can be reached.

Same Shape, Different Floor

Something is different anyway, and it is not what most people reach for. The usual answer is that the hardware improved, and it did. Better machines took over during the climb, spending less energy for the same work than anything running a cycle earlier. Left alone, that would make coins cheaper to produce and push this bottom lower than the last one.

The hardware was not left alone. Every improvement drew more machines in, and the protocol released fewer coins across the same stretch, so the work standing behind a single coin rose on both counts while the machines doing it got better. Two things step here, and they step in opposite directions. Work behind a coin rises whenever a gap pulls capacity in. It can ease afterward as machines switch off, and it does not return to where it started. Energy per unit of work drops whenever a

better machine takes over, and that does not reverse either. What a coin costs is the two of them multiplied.

Which one won this round is a question with an answer, and over a full turn of the cycle the competition usually takes it. Hardware improving is itself what draws the competition that outpaces it. So a coin ends up costing more energy to produce than it did a cycle ago, not by a law but by a tendency that holds when the gap was wide.

> *The bottom feels the same because the story around it is the same. It lands somewhere different because the machine underneath it already changed, and the competition for it got harder.*

That is the whole of it. Production cost is a floor under price, and the floor is higher than it was. The bottom lands higher because coins genuinely became more expensive to make, not despite the hardware improving but because of what the improvement attracted.

Measuring It From the Top

Floor is the right word only at the right distance. Price does dip below the cost of production, and has, in spikes that return almost immediately. Those come from outside the mechanism rather than inside it, a shortage of cash somewhere repricing everything at once, not anything competition or efficiency did.

Two things bring it back. Only half the ratchet can be touched that way, since a squeeze on liquidity does not unwind anybody's accumulated holdings, so the coin side stands while the mining side is briefly shoved. And the shove changes what somebody will pay this week rather than what a coin costs to make. Zoom out to the span the rest of this book works in and the dips are wicks on a level that held.

Now take each bottom in turn, and be careful which number you hold them against. Not the previous cycle's price, which says nothing about whether anything underneath changed. And not the joule limit either,

since that steps the other way and would make every cycle look like a retreat. The figure that answers the question is what a coin cost to produce at each bottom, and comparing those two is where the progress shows.

The Same Floor, Reached by More People

Something else deserves saying about a second bottom, because the phrase higher low can mislead about what actually recurs.

What grew is on the other side of that sentence. More machines reaching it. More operators reaching it. More total energy having been spent to produce coins that are fewer in number than the ones the previous cycle produced. The floor is not higher because the condition got easier. It is higher because a larger, hungrier system now has to be fed before that same condition can be reached at all.

> *Every bottom ends in the same place. It just takes more of everything to get there.*

Both ratchets show up in that sentence, doing different work. The rising cost of production is why the floor sits where it does. The rising base of held coins is why fewer of them are available to push it back down. One raises the bar and the other thins what could be thrown at it, and neither undoes itself when the cycle turns.

Why This Is Not an Accident

It keeps happening for a specific reason, not luck. Competition can bid a machine's price up and down as often as a gap opens and closes, and that motion reverses freely. What does not reverse is the accumulated work standing behind a coin. Machines that entered during the climb run until they stop paying, and then they are parked rather than scrapped, so the capacity is still there when a price returns. Issuance never returns to an earlier rate at all. So the effort behind a coin holds its ground through the fall and starts the next climb from there.

Both halves of the mechanism's name apply here, each to its own half of the story. The fast, repeating part, coins and machines changing hands while gaps open and close, behaves like an engine. Cycling, reversible, returning near its start each time. The slow part behaves like a ratchet, permitting motion one way only, and what moves that way is the cost of producing a coin. Across full turns of the cycle it climbs, because every improvement in hardware pulls in more competitors than the improvement itself displaces. Better machines push the other way and can win a stretch outright. They have not yet won a cycle.

So the second bottom lands higher, neither by luck nor by design, but because the fast part ran its course while the slow part quietly did what it always does. Carry that forward as the central claim of everything after. The story repeats. The floor beneath it does not.

CHAPTER EIGHT (A)

All Volatility Must Balance

Everything in the last seven chapters, said again, in four phases that return to where they began

Seven chapters have walked one full turn of this story, plus enough of a second to prove where it lands. What follows compresses the shape into a single pass, naming each phase and filling in two things that were true throughout but never said outright.

Every turn of this machine runs the same sequence, and it has now run one and a half times in plain view without being drawn. Something opens a gap. Capital sees it and commits. The world takes months to deliver what the capital ordered. The delivery closes the gap, and the closing is itself the next cause.

Nothing in that chain is optional and nothing in it is fast. The lag is not a friction to be engineered away; it is the reason the cycle exists at all, because a response that arrived instantly would never overshoot and there would be nothing to describe. Every phase in this book is one link of that sequence, seen from whichever side happens to be moving.

Hot Coins, Hot ASICs

Start at the top, where both sides run hot at once. This happened once at the beginning, the first time price ever met a mining cost, with machines already doing the work before anyone quoted a number. It has happened at every peak since for ordinary reasons, and those are the ones to trace.

New machines arrive in volume. Competition among manufacturers sharpens, since several shipped into the same opportunity. Coins sell for

two distinct reasons at once, traders taking profit and miners converting coins into machines to chase more of the same reward. Whatever drives any single sale, redistribution starts here, coins moving from wherever they sat toward wherever the opportunity is.

Inside this phase sits the stretch people mean when they say bull run.

Picture the climb as one continuous curve rather than a series of jumps. Price starts slow, building as any trend does before outsiders pay attention. What this book calls the bull run is not the whole climb. It is the steepest, most vertical stretch, where mining capacity has hit its constraint and buying the coin is the only lever left. What follows, once new hardware lands, is the same curve easing off its peak angle.

A moment of its own, distinct from what came before. Used hardware thins as available machines get bought. New orders pile up, but a physical lag separates ordering, manufacturing, and shipping, and that lag does not shrink because demand grew. For a stretch, hashrate cannot grow as fast as appetite for it.

During that stretch one route to exposure remains. Buy the coin directly on the open market. That is the engine behind what people call the bull run, and it happens here rather than elsewhere in the cycle for a reason. Demand arrives faster than mining capacity can answer.

The lag has one further effect on new-machine pricing. Whoever ships working units into this stretch first becomes the price-setter, briefly, since every rival still has product in transit or on the line. That first price is what the rest must compete against when their shipments land.

> *For a while, there is only one lever left to pull. Everyone pulls it at once.*

Cold Coins, Hot ASICs

Price stalls, then slides. Hardware ordered during the lag catches up to the opportunity that justified it and then overshoots, hashrate racing upward while the reward stops growing. Difficulty rises to match, and the least efficient of the widened population start switching off. They do not outnumber the arrivals, so hashrate keeps climbing even as machines begin leaving, which is the whole character of this phase: everything underneath has turned while the total still rises. ASIC prices fall, new and used alike, and fall faster than profitability does because the leavers are selling into the same market the manufacturers are. Cost tips back from capex toward opex, the reversal described earlier.

Cold Coins, Cold ASICs

Both markets go quiet. The bottom, described at length already. Coins go quiet because nobody has reason to move them, hardware because both sides ran out of reasons to trade, and the two arrive at that state by separate routes.

Two markets absorb the excess a hot phase throws off, not one. Secondhand machines soak up the hardware, capital and urgency, the role already described. Held coins do the same on the other side. Through the climb, holding thins out and trading volume swells, and that volume is the coin market running hot. It cools by draining back into storage, and volume falls as it goes. Note the asymmetry between the two. New machines can flood a market, arriving in bulk from every manufacturer at once. Newly issued coins never can, since the protocol releases them at a rate no one can hurry. Only coins already held can flood, and only if price offers enough to pull them out.

Hot Coins, Cold ASICs

The cycle closes where it reopens. Machines that survived the bottom sit cold and idle, not yet worth switching on, while the coin starts moving before they do.

Coin price rises. Profitability follows at once, since the same running cost now earns more. It surfaces first as a shortening payback, a machine covering itself faster than expected, long before anybody builds anything.

After a short lag, the shortened payback makes idle and used hardware interesting again, and prices for both used and new units get bid up as more people notice the widening gap.

CHAPTER EIGHT (B)

What Does Not Reset

The cycle returns to its start. Two things underneath it do not

Four phases, and the fourth hands back to the first. Run that loop as many times as you like and it keeps arriving where it began. Something is still different each time around, and it is not in the loop.

Two Ratchets

Two mechanisms in this book earn the word ratchet, one on each side of the market, and neither collapses into the other.

Both are fed by the same thing, which is easier to see before they are named. Every gap this book describes gets answered with machines, because a visible margin is a reason to buy hardware and hardware is what closes a margin. So the fast cycle does not merely spin. It converts, turning a distance between two prices into silicon that outlasts the distance. Whatever the cycle extracts leaves it in that form, which is why anything accumulates at all.

Neither ratchet is a fifth phase beside the other four. They run underneath all of them, at different speeds. Hardware improves in discrete jumps, and only when a newer machine beats the incumbent on total cost, which a cheap secondhand machine can hold off for a long time. Competition never waits for a clean moment. It grinds on continuously, and holding accumulates without pause, a little more staying put at every bottom. The cycle keeps returning to the same four shapes. What sits underneath them does not return to anything.

The first sits on the mining side: what it costs to produce a coin has climbed across every cycle so far, and has not handed the ground back. That number repays a closer look, because it is not one quantity rising. It is two stepping in opposite directions, and the cost is what is left after they meet.

Work behind a coin rises when a gap opens. Profitability becomes visible, machines get ordered, and months later they arrive and the effort standing behind each coin steps up. Through a descent it does not step back down, because hashrate leaves at roughly the rate issuance shrinks and the two cancel. It holds where the last hot phase left it and waits for the next one.

The other force steps downward. What a machine spends per unit of work steps down in jumps, when something wins on total cost and takes over as the workhorse. No individual machine improves. Silicon that has been built does not become less capable, and never becomes more so. That step is always downward and it never reverses.

> *Two step functions pointing at each other. What a coin costs is the score after both have moved.*

So the cost of producing a coin is those two multiplied, and its direction in any given round belongs to whichever stepped further. A gap that pulls in more competition than the next machine can offset leaves the cost higher than it started. A quiet stretch with a good machine arriving leaves it lower, sometimes markedly, which is what a long descent with better hardware looks like from the inside.

Two questions sit under that. Whether a gap reopens at all, and whether competition beats silicon while it is open.

The first has a structural answer once a network is established enough to hold a floor of demand. Some quantity of buyers persists through anything, on faith or understanding or because they have a use for the thing. Meanwhile both sources of supply thin. Market supply thins because holding accumulates at every bottom and never fully unwinds. Mined supply thins because issuance falls on a schedule that does not answer to conditions. Demand holding above zero against supply trending toward it does not make a gap likely. It makes one a matter of when.

The second is a question about clocks. Capital answers a visible margin in months, because ordering machines is a decision anybody can make on a morning. Silicon answers on the schedule of design and fabrication, which is years. So inside any widening gap the competition arrives first and arrives in quantity, and the improvement that eventually shows up is answering conditions that have already changed.

> *A gap has to reopen because supply keeps thinning and demand does not vanish. While it is open, capital moves faster than fabs.*

Each gap is smaller than the one before it. A larger cost base means the same arriving demand opens a narrower distance, and more capital is already deployed and ready to answer. So the ratchet advances in shorter steps as a network matures. It still advances, because a shorter step is still a step and nothing carries it back.

Across full turns of the wheel the competition tends to win, because it arrives both faster and in greater number than the improvement that summoned it. Fewer coins get produced, more effort chases each one, and there is always a bigger fish. But it is a net of two opposing steps rather than a single force grinding one way, and any given stretch can run backward.

The second sits on the coin side. At every bottom, cost basis straddles current price, roughly half the circulating coins in profit and half underwater, each half holding for its own separate reason. Holding jumps here, and it never fully unwinds when price recovers. Some portion of what crossed into long-term storage at that moment stays there, gone from circulation, the pattern visible in how rarely the oldest coins ever move again. Not physical, not mechanical, real regardless, and pointing where the first points: one more thing the local cycle produces that never comes back.

> *One ratchet makes each coin harder to produce. The other makes fewer of them available to buy. Both only move one way.*

Both run together, and they compound rather than cancel. One raises what a coin costs to make. The other shrinks what is available to buy.

Neither reverses when the cycle turns, which is why the next bottom cannot land where the last one did.

The Story Ends Here

That closes the story half of this book. Every mechanism named across these eight chapters, forced convergence, the used-hardware market, the two forms of compression, the two ratchets, has been described in words, with no number attached to any of it.

Which Networks This Describes

One caution before the numbers arrive, because the preceding chapters have said nothing about which networks any of this applies to, and silence there could be read as saying it applies to all of them equally. It does not.

Every proof-of-work network has something engine-shaped in it. Demand on one side, cost of production on the other, work extracted from the distance between. That much comes with the design. What differs is how much of the work survives the trip, and the differences are large enough that two networks running identical machinery can produce quite unequal money.

A supply cap is the version of this everybody knows, and it is the least interesting one. Debasement does not require printing. A network can leak value in several ways that never touch its issuance schedule, and a cap tells you nothing about how many of them it is leaking through.

> *A hard cap tells you nothing about how much of the work is reaching the other side.*

Both ratchets assume a network where the mechanism runs cleanly. A network leaking value somewhere ratchets less, or not at all. Naming the leaks individually and weighing them against each other is a subject with a shape of its own, and it belongs in The Instrument under Degrees of Soundness rather than here.

So read what follows as describing networks whose machinery is intact. Where it is not, the same parts are present and some of the output goes missing on the way out.

PART TWO

The Mechanism

The same story, now given units

Everything in this part assumes the block reward is the only revenue a miner receives. Fees exist throughout, but while the subsidy is large they stay small enough to leave out of the arithmetic. The next part shows what a second revenue stream does to the figures, and why the change is smaller and more self-correcting than it first appears.

CHAPTER NINE (A)

What a Machine Makes, What a Coin Takes

Everything in the last eight chapters happened in words. This is the unit

A joule is a small amount of energy. A kettle pulls roughly two thousand every second it runs. A phone charging overnight consumes a few tens of thousands. A mining machine, left going for a day, burns hundreds of millions.

Part One leaned on this unit throughout without ever pinning it down.

What a Machine Makes

The first quantity is joules per hash: the energy a machine spends performing one unit of work. Part One gave this a name and used it for eight chapters. It is the joule limit, now with a unit attached.

It is a physical property of the hardware rather than a sentiment, and it does not shift because the market turns excited or afraid. A machine built to spend a given number of joules per hash spends exactly that, hot or cold, until something better physically replaces it. Two machines can look alike and differ enormously on the figure, and the difference explains a good deal of what Part One described. The more efficient one does identical work for less energy, so it survives at prices that finish other people.

Across generations the figure only ever falls. Silicon gets better at the same task and never worse, so the best number available today is lower

than the best number available last time, and the one after that will be lower again.

What a Coin Takes

The second quantity runs the other way, and setting the two side by side is the whole of what this chapter is for. Hashes per coin: how much work the entire network performs for each coin the protocol releases.

Nothing about a machine determines this one. It is set by how many machines are competing and how hard the network has made the puzzle in response, which Part One spent eight chapters showing is set by price. Add competitors and each coin has more work standing behind it. Thin the issuance and the same work divides across fewer coins. Both push the figure up, and neither has an equivalent pushing it reliably down.

Multiply the two and the result is joules per coin, the energy behind one unit of what the network issues. One term falling because silicon improves, one term climbing because capital arrives, and the product of them is what a coin costs to produce in energy. Which of the two won any given round is what decides whether coins got cheaper or dearer to make, and Part One answered that question without once naming the terms.

The Workhorse Sets the Number

At any moment, machines of many ages and efficiencies mine simultaneously, and their average is not the number that matters.

The obvious candidates are the best machine and the worst one, and neither works. The best in existence may be running almost nowhere, newly released and barely deployed, earning a wide margin for the few who have it and setting nothing. The weakest survivor is beside the point too, hanging on at the edge and doing a rounding error of the work. Sometimes the most efficient machine does set the number and sometimes it does not, which is the clue that raw efficiency is not what decides.

What anchors the cost is the workhorse: whichever machine won on total cost and therefore got bought in bulk. Capital piles into that machine, so it ends up performing most of the work on the network, and what it spends is the closest thing the network has to an average cost of producing a coin. A better machine existing changes nothing until it takes that position, and it takes that position by being cheaper to own and run than the incumbent, not merely by being more efficient.

Price falling still matters, and it matters differently. The weakest survivors exit first, which is what sets how far price can fall before supply starts leaving. That is a question about the floor's location. The workhorse is a question about what a coin costs. Two different questions, and the answers are usually two different machines.

Efficiency alone does not decide which machine becomes the workhorse. Two miners on identical hardware face wildly different outcomes if one pays three cents per kilowatt-hour and the other twelve. Cheap power tolerates a worse machine. Expensive power demands a better one to stay level. Nor is power the only threshold. A machine has to fit what most operators already have, the voltage on the wall and the rack it has to sit in, and a design that needs something rarer than that will not be the one most of the network runs. The winning position comes from the combination, and whichever miner is weakest on both is the one whose exit moves the number.

And the bill is larger than the chip. Housing a machine, keeping it cool, and getting power to it all cost something, and all of it lands on the same line as the electricity itself. The workhorse is never quite a chip. It is a chip somewhere, under a power contract, and the somewhere is part of the number.

The Machine Has a Joule Cost of Its Own

So far this counts only the energy a machine spends while running, which is half the picture.

A machine already sitting in a warehouse costs pure opex, whatever it burns from here forward. Nobody starts there. Somebody built it first, and

building was not free. Refining silicon, etching it into a working chip, assembling the board, all of it consumes energy long before the machine hashes anything.

It is not a rounding error either. Machines converge on their manufacturing cost the way coins converge on theirs, competition stripping the excess until price sits near what the thing costs to make. The same movement, one level upstream. Building a machine and running one draw from the same well. Not two kinds of spending. Two stages of the same production.

> *Mining a coin is brute-forcing a hash until one satisfies a condition. Building the machine that does the mining is refining raw material into ordered structure, one careful layer at a time. Both are production. Both cost joules. Neither is free.*

So the complete joule cost of one coin exceeds the energy spent running the workhorse. Add a share of whatever energy built it, spread across every coin it will produce in its working life. Skip that and the figure describes only somebody who already owns hardware. Include it and it describes what entering from nothing costs.

Which raises the obvious question. Spread across how long?

A working life is not a specification printed on the box. Nothing wears out on schedule. A machine stops working when it stops paying, the moment what it earns no longer covers the power it draws, and that moment is decided by the cycle rather than by the hardware. Bought into a widening gap, a machine runs for years. Bought into a closing one, it can stop paying inside a season. Identical silicon, wildly different divisors.

There is a cleaner way to mark the endpoint. A machine that cannot cover its own power is worth nothing to anybody else either, since whoever bought it would face the same bill. So the working life runs from purchase until resale value reaches zero, and the used market sets that date, not the manufacturer. However many coins come out across that span is the divisor, and the whole of the manufacturing energy is spread across it.

Run that to its conclusion and something tidy falls out. A miner paying the network average for electricity, from purchase until the machine is worth

nothing, puts in a total that matches what comes out. Capex plus opex on one side, coins received on the other. Cheaper power and they keep the difference. Dearer power and they are funding somebody else who keeps it.

Doing the Actual Arithmetic

Four questions get you there, and they can be answered in order without holding anything in your head.

How much work does the machine do? How much work is the whole network doing? Those two give the machine's share. Divide the coins the protocol releases by that share and you have how much work stands behind one coin, for this machine, at this difficulty. Then ask what that work costs at the rate the marginal miner pays for electricity, and the answer is money.

Nothing in that sequence is negotiable, and none of it is fixed. Every term moves. The share falls when competitors arrive. The work behind a coin climbs when they do, and climbs again when issuance thins. The electricity price is whatever the operator negotiated. Change any of them and the answer changes with them, which is the point rather than a complication.

One rate at the end of that sequence matters more than the rest, and it is not today's. It is the electricity price at which this machine breaks even and keeps breaking even, holding at zero across a long stretch while hashrate falls with price and issuance falls on schedule. That figure is what a miner is actually betting against when they sign a power contract, and it is the only version of the number that survives contact with a full cycle.

None of this includes the machine itself, the second half named a moment ago. Everything above is running cost, the energy going in from here. Why the other half has to be handled separately, and what it does to a miner who cannot know its size in advance, comes later.

CHAPTER NINE (B)

What That Number Obliges

A settled cost is not a neutral fact. It decides how much of what a miner produces has to go, and to whom

A figure now exists for what a coin costs to produce. What follows is what that figure does to whoever is standing underneath it.

How Much Has to Go

Fix the workhorse, the electricity it runs on, and the work the network currently demands per coin, and the cost of producing a coin stops being a question. All three are known quantities at any given moment, and multiplying them settles the question. The number sits there waiting, whatever the market happens to think.

What the market decides is how much of the production a miner is obliged to sell. A miner is not choosing between selling and holding out of temperament. Electricity is billed continuously and the bill does not wait. Coins get sold to cover it, and the only question is what fraction that takes.

Hold price well above the cost of production and the fraction is small. A miner covers the bill with part of what they mine and keeps the rest, and plenty do exactly that. Let price fall toward the cost of production and the fraction climbs, because the same bill now consumes more of what the same machine earns. At the floor, the miner sitting at the margin has no fraction left to withhold. Close to everything mined has to go, immediately, simply to keep the machines running.

> *Nobody at the margin is choosing to sell. They are selling because the alternative is switching off.*

Which sets a ceiling on how much selling the network can produce. A miner cannot sell more than exists to be sold, and what exists is whatever the protocol released. When price sits at the cost of production, essentially all of that new issuance reaches the market and the pressure is at its maximum. That maximum is not fixed, though. Issuance shrinks on a schedule no one controls, so the largest forced sale the network is capable of gets smaller with every cycle. The pressure that defined earlier bottoms cannot define later ones with the same force.

Every market of consequence has a participant who acts when nobody else will. In a currency it is the central bank, and its defining feature is that its capacity has no ceiling: it can supply money without limit, and can make money cheaper to produce at the same time. Miners occupy the same structural position with none of the freedom. They go on transacting after everyone else has stopped, because the power bill does not pause for a bad market, and what they can supply is issuance and fees. Nothing else, ever.

Both of their levers point the wrong way for relief, too. Issuance only declines, and the cost of production climbs as competition arrives. Where a central bank facing strain can supply more at lower cost, a miner facing strain supplies less at greater cost. And the effect inverts with the position: a lender of last resort supports a market by putting money into it, while a seller of last resort pressures one by putting coins into it. A bottom is made by the only participant who cannot stay out.

The Real Numbers

That single calculation drives everything Part One described in words. The gap opening, the crash, the stillness, the recovery, all of it was this number moving, or price failing to keep pace with it.

That money figure comes apart into its own pieces, since paying for a machine and paying to run it are not the same kind of cost, and neither of them is the same as the cost of simply having to wait.

CHAPTER TEN

Capex, Opex, and the Cost of Waiting

Two costs, two currencies, and only one of them is measured in joules

Manufacturing a machine consumes energy, the identical kind of cost as running it. Follow that to its conclusion and something appears alongside it that energy alone cannot explain.

Opex Paid Upfront

Capex is opex paid in advance, not a separate category sitting outside this book's logic.

Every dollar that went into building a machine, refining silicon, assembling the board, shipping it, is energy somebody already spent, bundled into one price and handed over at once. The buyer is not purchasing a different kind of cost from the electricity bill that follows. Same cost, already paid, on a different schedule.

That leaves a miner one choice this book has not yet named. How much of the total to pay now, how much later. An expensive, efficient machine bets on more upfront and less over time. A cheap, inefficient one bets the other way, less now, more spread across every future kilowatt-hour. Both can land near the same total, drawing from the same well.

> *A miner is negotiating with the network over one total. The only question capex and opex settle between them is timing.*

Two Premiums, Not One

Once that lands there is a temptation to treat every price above physical cost identically, coin and machine alike. A useful distinction sits underneath that.

When a coin trades above its joule cost, the premium is a direct bet. An outside buyer with no stake in mining pays more than physical cost because they expect the coin scarcer, or more valuable, later. Mining explains none of it. The premium arrives from outside the system.

When a machine trades above its manufacturing cost during the same hot stretch, something else drives it. The buyer is not betting the machine is scarce in any lasting way. More can always be built. The buyer is betting on the coin's premium and bidding up the machine because it is the fastest tool for capturing that bet before somebody else does. The machine's premium is real but not original to it. Inherited secondhand from the coin, transmitted by competitive urgency, the willingness to overpay simply to arrive first.

One premium is direct, the other derived. Coin scarcity funds machine scarcity and never the other way round, even in the stretch when machines are the scarcer of the two, because what a shortage of machines does is push the demand onto the coin. The distinction explains why an elevated machine price collapses faster than an elevated coin price. A derived bet unwinds the instant the thing it depends on stops paying. A direct bet can survive on belief long after.

A derived premium runs the other way too. When the coin's premium collapses, nothing independent holds the machine at its manufacturing cost. A desperate seller, still facing the continuous electricity bill described earlier, takes less than the machine cost to build simply to escape before the next bill. Briefly the machine becomes salvage, priced by what somebody will pay to be rid of it rather than by what it might earn.

The Other Currency

Capex and opex together cover every joule spent, upfront or across a working life. Neither covers what a miner takes on the moment they commit to either, which is the wait before the spending returns.

That wait is not a third cost sitting awkwardly beside the other two. It is the other currency, and the other two were denominated in it all along. Everything here is bought with resources or with time, and usually with some ratio of the two. Choosing capex over opex means choosing to spend sooner rather than to spend more, and the extra buys a shorter wait.

> *Pay more and wait less. Pay less and wait longer. A premium is the exchange rate between them.*

That is what a premium on a machine actually is. Nobody pays above manufacturing cost for better silicon in the abstract. They pay for the months it takes off the front of the return, and the price of those months is set by how badly everyone else wants the same thing at the same moment.

Time has a second face, though, and this one you do not spend. You are charged it whether or not you bought anything. A miner paying up for a shorter payback only wins if the payback lands on schedule. Let difficulty keep climbing while it runs, as more of the same hardware arrives behind them, and the return falls short of what the purchase assumed. The machine cost what it cost. The energy bought what it bought. Time was taken from them rather than sold to them.

The purchase price has not changed. The electricity price has not changed. What changed is the exposure carried for the extra months, and none of it appears in the capex figure or the opex figure. It appears only in how long the wait turns out to be.

What the Waiting Actually Costs

So producing one coin is paid for in two currencies, not three costs. Energy spent building the machine and energy spent running it are the

same currency on two schedules. Time is the other, and it buys the schedule.

Time takes a definite shape here, now that the second half of the calculation has a name. Manufacturing energy gets divided by however many coins a machine produces before it is worth nothing. Nobody knows that number at purchase. They estimate it, they pay a price built on the estimate, and the cycle decides afterward whether the estimate held. Time here means the uncertainty sitting in a divisor that has already been committed to, which is a good deal more concrete than unease about the future.

Calling it a risk undersells it. A risk is something that might happen. Every machine ever switched on has been running toward obsolescence from the first block it worked on, and the only open question is how fast. Somewhere a design is being taped out that will make this one uncompetitive. Somewhere hashrate is being added that will thin its share. Neither event needs to have happened yet for the machine to be worth less this month than last.

> *Nothing has to go wrong for a machine to be dying. It is dying on schedule, and the schedule is not published.*

What makes this bite is that the clock ignores the power switch. Idle a machine through a bad stretch and it keeps losing value at the same rate, because what erodes it is happening elsewhere, in fabs and in other people's deployments. Switching off saves the electricity and saves nothing else.

It explains why miners run at margins that look irrational from outside. A holder waiting out a weak market is holding something that will still be there afterward. A miner waiting out the same market is holding something that will be worth measurably less when it ends, and might be worth nothing. Waiting is not free for them and never was. It costs the machine. So they mine at thin margins, sell what the bill demands, and keep the thing earning while it still can, because the alternative is watching it expire quietly with nothing to show.

Both ratchets named in Part One run through this calculation, though only one appears in it directly. Rising production cost is the figure being calculated here, pushed up by difficulty as competition arrives and pulled

down, more slowly, as better hardware takes over. The coin-side ratchet never enters the calculation at all, because it acts on how many coins reach the market rather than on what any of them cost to make.

Which leaves one force unaccounted for, the only one capable of lowering what a coin costs a miner to obtain without anybody building a single new machine.

PART THREE

The Fee Correction

A second revenue stream, named and left

This part is deliberately short. Fees are a large subject with dynamics of their own, and following them properly would take far more room than this argument needs. What matters here is that they exist, that they change the arithmetic Part Two established, and that they regulate themselves back into the cycle already described.

CHAPTER ELEVEN

The Fee Correction

A second stream of revenue, what it does to the arithmetic, and why it corrects itself

Part Two built the cost of a coin out of the energy behind it and treated issuance as the whole of what a miner earns. That was accurate and incomplete, and the missing piece is minor while the subsidy lasts and eventually everything.

What a Fee Does to the Number

A miner spends energy to find a block. The reward for that has been treated so far as one thing, the coins the protocol releases. A fee adds a second stream to the same block, paid by whoever wanted their transaction carried, and the machine spent no extra energy earning it. Same joules, more coins to the miner. Divide the energy by the total and the cost behind each coin falls.

Nothing was created doing that. Supply and demand are unchanged, so the coin is worth what it was worth; the miner simply ends the block holding more of them, and the extra came from somebody who already had them.

Which means the figure just quoted is not quite the one Part Two built. There it was energy measured against coins the protocol issued, since issuance was the only thing a miner received. With a second stream arriving, the number that decides anything is energy measured against coins the miner ends up holding, however they arrived. The two diverge the moment fees are more than a rounding error.

The second is the one that matters here, and the reason is what the number is for. Cost of production is the level below which mining stops paying for itself. What decides that level is everything a miner earns set against everything a miner spends, and a fee is earnings. A miner collecting fees survives a lower price than one who is not, so the floor genuinely sits lower. Whatever arrives as fees is that much less that has to come from price, two sources filling one requirement rather than one source growing.

Two things about the fee are easy to get wrong. It does not lower the joule limit, which is what one machine spends to do one unit of work and answers to silicon rather than to revenue. And it does not last, because a better return pulls machines in the way every better return in this book pulls machines in, until the work behind a coin has climbed enough to swallow it.

Fees Do Not Wait for Congestion

There is a common assumption that a fee market switches on when a network fills up, and stays dark until then. It does not work that way. Anyone wanting a transaction carried pays the least that gets it carried, and that floor is not zero. Where there is activity there is revenue, whether or not anybody is competing for position.

> *A network does not need to be full to be paid. It needs to be used.*

Competition adds to that rather than creating it. Somebody holds information that will not stay private. Somebody is moving to capture a price that is closing. Somebody has a transaction worth less the later it lands, and somebody else would simply rather not wait. All of them pay above the floor for one reason: what they are buying is time, the same purchase a miner makes when paying a premium for a machine that pays back sooner.

The distinction matters for one reason only. It means fee revenue tracks how much a network is used, not how badly it is strained.

The Handover

Two streams pay for security, and they run on incompatible schedules. One shrinks on a schedule written into the protocol and answerable to nobody. The other grows or does not, depending on whether the thing gets used.

Issuance is largest when a network is young and least used, which is exactly when fee revenue is smallest. Fees become substantial only once enough activity exists to generate them, by which point issuance has faded. Somewhere between those states the two lines converge and wobble against each other, fees above in a busy stretch and below in a quiet one, before parting for good because only one of them can fall. How long that wobble lasts is not fixed. A steep issuance schedule makes it brief and a slow one draws it out. What is not in question is the direction. Issuance falls on a schedule nobody can amend, so given persistent demand for blockspace it ends up beneath fee revenue eventually, whatever the numbers look like on the way.

> *The subsidy is a set of training wheels. Nobody puts them back on a rider who can balance.*

Whether any network completes the crossing is not something this book can settle, and nobody should pretend otherwise. It has not been done. If some network has crossed by the time this is read, it will be the first, and the fee side of every budget before it was small enough that the subsidy did the carrying.

Why It Corrects Itself

A reader who has followed the cycle this far will already suspect that a second revenue stream cannot simply grow without something pushing back. It cannot, and the pushing back is the same machinery working on new material.

Let fee revenue grow past issuance. The cost behind a coin falls, because the same joules now put more coins in the miner's hands. A lower cost lets

miners accept a lower price and still survive, which means selling into the market at levels that would have finished them before. Cheaper coins and a flat price discourage moving, because there is nothing to realise by moving. Less moving means fewer transactions, fewer transactions mean less fee revenue, and the cost behind a coin climbs back toward where it was.

The thing that lowered the floor removed its own cause. And it runs the other way too: heavy use hands miners more coins to sell, that selling cools the market with the lag every effect in this book arrives with, and the cooling eventually leaves room for price to rise again.

> *Fees do not escape the cycle. They join it, and the cycle does to them what it does to everything else.*

Somewhere far out, that balance settles. Fee revenue stops swinging with price because price stops swinging so hard, and what remains is activity generating revenue at a rate the network can be paid on. That is a description of a store of value that has finished emerging, which is the far end of the thing this book has been describing rather than a part of it.

Why This Chapter Is Short

Everything above could be followed a great deal further. Fees do not vanish into the protocol; they reach miners, who sell them the way they sell everything else, so a large fee market moves a great many coins out of hands that could wait and into hands that cannot. That interacts with the holding side, with the forced seller, with the cost of production, and each interaction has its own lag and its own overshoot.

None of it changes what this book set out to describe. The corrections resolve back into the same four phases and the same two ratchets, which is why they can be named and left rather than followed. A mechanism that regulates itself back into the cycle is part of the cycle. One thing does not wash out, though, and it is worth flagging before leaving the subject. A fee market that runs hot for long enough is a gap like any other, and gaps are answered with machines. Those machines are still there when the

revenue that paid for them has gone. The price effect cancels. The hardware does not.

What the fee correction adds is one qualification to Part Two and one open question for the end. The qualification: the cost of a coin is lower than the issuance-only figure suggests, by however much fee revenue currently runs, and that discount is competed away like any other. The open question is whether the handover completes, and that belongs with the rest of what is still unsettled.

CLOSING

What Holds, and What Doesn't Yet

The name, tested, traced to its source, and closed with an account of its limits

CHAPTER TWELVE

What This Is Called, and Why

A name stated at the start is a promise. A name earned at the end is a conclusion

This book opened under a name it had not yet earned and said so at the time. Now the moment has come to return to that name and ask whether everything built since still supports it, or whether something broke quietly along the way.

The Local Half

A Carnot cycle returns to its starting state, phase for phase. Chapter seven tested that against the four-phase cycle this book had walked twice by then, hot machines meeting a new price, the rush behind it, the stillness at the bottom, the climb back out. The claim held. The local cycle lands close to where it began.

Everything built since left it standing. Part Two gave the cycle units, joules per machine, joules per coin, capex as prepaid opex, without altering its shape. Part Three added a second revenue stream, and every test landed identically: a fee-driven profitability gap behaves like a price-driven one, competed away by the same local mechanism on the same local clock. The fee lever moves fast and reverses. It never reached the slow half.

The Global Half

A ratchet moves one way. Two things here do, and they move in opposite directions, which is why naming this half takes a moment longer than naming the other.

The joule limit steps down. What a single machine spends to do one unit of work only ever improves, and only steps when a better machine becomes the workhorse by winning on total cost. Silicon that has been built cannot become less capable. That movement is downward and it never reverses.

The work behind a coin steps up. Every improvement in hardware pulls in more competition than the improvement itself displaces, and the machines that arrive do not leave when the gap that summoned them closes. Issuance thins on a fixed schedule, so the same effort is divided among fewer coins. That movement is upward and it never reverses either.

> *One ratchet lowers what a machine spends. The other raises what a coin takes. Across every full turn observed so far, the second has won.*

Multiply the two and you have what a coin costs to produce, and that product is what the global half of the name is about. Across full turns of the cycle it climbs, because every improvement calls in more competitors than the improvement displaces. Better hardware pushes the other way and can win a stretch outright. It has not yet won a cycle, and whether it eventually does is a question the closing chapter puts plainly rather than settles.

So Brownian global points upward, and that is the claim needing the hardest stress-testing. A rising fee was the strongest candidate anywhere in this book for something capable of reversing it. It cannot, and the reason follows from what every gap does. A fee widens one, and a gap wide enough for long enough gets converted into machines like any other. Those machines lay track. So a sustained fee market does not push against the upward movement, it feeds it, adding to the work behind a coin exactly as a price-driven gap would. The revenue washes out with the cycle. The hardware it paid for does not.

> *Every test run against the name tried to break one half or the other. Neither half broke.*

Why the Split Was the Right Call

One descriptive word for the whole mechanism would have been simpler, and wrong. Any single term covering both halves would have to pick cycle or ratchet, and the honest answer is that this is one machine behaving differently depending on how long you watch it. Neither half was bolted onto the other.

Locally the same conditions recur. Machines get bid up, coins get sold, both markets fall still, and it starts again, because no single turn permanently alters what the next turn looks like. Globally two things change permanently every turn, in opposite directions, and no mechanism anywhere in this book can undo either. What accumulates is the difference between them.

What Is Left

So the name holds, tested against everything built since it was first called unearned. Carnot local, because the fast half returns to where it started. Brownian global, because the slow half never does, and because the direction it fails to return in is upward.

Both names came from thought experiments, neither of which was ever built. Where they came from, and what remains unsettled, is what is left.

CHAPTER THIRTEEN (A)

The Engine Nobody Can Build

A name can be earned without showing where it came from. This is where

The name has been tested against everything built before it and it holds. What that test never did was say where the two names come from, or point at which part of the network plays which part. Both come from thought experiments, neither of which was ever meant to be built, and that turns out to matter.

What Carnot Described

A Carnot engine cannot be built. Sadi Carnot described it in the eighteen-twenties as an idealisation, an engine with no friction, no leakage, nothing wasted anywhere, precisely so he could work out the most any heat engine could possibly achieve. Every real engine falls short of it. That was the point. It is a ceiling, not a blueprint.

On paper it has four parts and runs four stages. A hot reservoir and a cold reservoir sit at different temperatures. Between them, a working substance, usually a gas, drives a piston. The gas expands against the hot reservoir, absorbing heat and doing work. It expands further, cut off from that reservoir, cooling as it goes. It compresses against the cold reservoir, shedding heat. It compresses again, isolated from both, until it arrives exactly where it began.

That final detail is the whole point, and the whole reason this book borrowed the name. A Carnot cycle returns to its starting state precisely, every time. One full lap changes nothing about the next.

> *Carnot did not describe an engine anyone could build. He described the one nobody could beat.*

Where the Engine Lives Here

The hot reservoir is human demand itself, the urgency to transact and the wish to hold something that keeps its value, arriving from outside and indifferent to what anything costs to make. The cold reservoir is the cost of production, the joules a coin cannot be minted for less than. Everything the engine does happens between those two.

The working substance between them is hashrate, swelling as heat enters and shrinking as it leaves. The work extracted is not the coin itself but what the coin certifies: security, finality, a record of what happened and when, paid for in energy nobody can fake.

That mapping settles something the book has circled for chapters. A Carnot engine's efficiency depends on the distance between its two reservoirs and on nothing else. Widen the gap and more work comes out. Close it and the engine stops. The profitability gap is that distance. Which is why a bottom is not a mood or a failure of nerve. It is an engine at the end of its stroke, demand having fallen to meet the cost of production, with no temperature difference left to work across.

The idealisation earns its keep a second way, and this one is easy to miss. Carnot's engine is a ceiling nothing reaches, and what separates any real engine from it is friction, heat going somewhere that does no work. The same subtraction applies here. Effort spent on blocks that lose the race is friction. Rewards thinning as they route through intermediaries is friction. Every leak named at the close of Part One is the distance between a network and the bound it is working against.

Soundness gets a cleaner definition out of that than a supply schedule ever could. A sound network is one running close to the ceiling. A less

sound one has the same parts arranged the same way and loses more of the work on the way out. Neither is a different machine. One is simply further from the limit than the other.

CHAPTER THIRTEEN (B)

The Ratchet That Cannot Work

The second device is the one that fails, and the reason it fails is the reason this one does not

One half of the name is accounted for. The other comes from a thought experiment built to prove something impossible.

What Feynman Described

The second device needs more care, because the version most people know is the one that fails. Richard Feynman described a vane in one bath, jittering as molecules strike it from every angle, sharing an axle with a toothed wheel held by a pawl in another. It looks like it should turn one way and lock, converting random motion into free directed work.

It does not, and Feynman built it to show why. The pawl sits in the same noise as everything else. Without energy spent continuously keeping it rigid, it lifts as often as it holds, and the wheel drifts nowhere. The thought experiment exists to prove that directed motion from pure randomness is impossible. It is a demonstration of failure.

What runs in a proof-of-work network is not that device. It is the one that works, and the difference is the whole reason this book is not called Carnot Local, Feynman Global. A Brownian ratchet is the class of real systems that do convert undirected fluctuation into accumulating progress, and they manage it for an unglamorous reason: something pays, continuously, to hold the asymmetry rigid. The pawl is not free. It never was.

> *Feynman built a ratchet to prove it cannot work for free. This one works because it is not free.*

Name what does the paying here and the mechanism stops being a metaphor. Active hashrate does fall when price falls, and steeply. What does not happen is the machines being scrapped. They are switched off and put somewhere, capacity parked rather than destroyed, waiting for a price that justifies the power bill again. Most of the coins that went into storage stay there too, because moving them offers nothing at the bottom. Neither is a decision anybody makes collectively. Both are costs already sunk, holding the wheel against slipping back, and both keep holding only while something keeps funding them.

Where the Ratchet Lives Here

The vane, jittering with no net direction, is the local cycle. Price and hashrate run hot and cold, expand and compress, and land close to where they started each lap, the reversible-looking behaviour the naming chapter already tested.

The teeth and pawl are what stops the accumulated work from unwinding. Machines deployed during a hot phase can be switched off, and are, but they are not unbuilt, and the ones that come back come back alongside whatever the next phase added. Issuance thins on a schedule and never thickens. So the effort standing behind a coin can dip while capacity sits idle, and it does not return to where it was before the phase began.

A second pawl runs the other way, and naming only one of them would misdescribe the device. What a machine spends per unit of work steps down whenever a better one wins on total cost, and that step never reverses either. Two ratchets facing each other, both locked, and the wheel turns in whichever direction the stronger one pulls. Across full turns that has been upward: coins cost more work than they did, even as every machine making them got better.

The two temperatures are where the analogy needs care rather than enthusiasm. One bath is the market, fast and noisy, moving in minutes.

The other is the manufacture of a better machine, chip design and fabrication moving on a slow, deliberate schedule. The mismatch is real, and it explains something specific: why the limit moves in steps rather than sliding. Fabs deliver in generations, so the improvement arrives all at once or not at all.

What it does not explain is why the motion runs one way, and it would be convenient to pretend otherwise. Feynman's pawl slips backward because thermal noise can lift it, and only a temperature difference stops that. Nothing corresponding threatens this mechanism. A chip that has been built cannot become less capable, at any tempo. Speed the fabs up to match the market and the limit would still only descend, just more often.

> *This ratchet can be paused. It cannot be run backward.*

So the resemblance is close but not exact, and the difference cuts both ways. Against Feynman's device this one is more secure, since its asymmetry sits in physics rather than in a maintained gradient. It is also more fragile, because the thing that can go wrong is not reversal but cessation.

Feynman's two baths were independent. These are not, and the difference sets a limit on how long the ratchet keeps clicking. Nobody designs and fabricates a better mining machine on a schedule. They do it when the return justifies the cost of trying. Let the gap stay closed long enough and the next generation goes unfunded, not because physics forbids it but because the numbers do not support it. Lithography has a wall somewhere. The incentive has no wall, only a fade. The return on trying again thins until it is not worth anybody's while, and there is no moment anyone could point to and call it the end. The wheel does not stop so much as slow past noticing, and it holds wherever it got to until a market hot enough to fund another attempt comes along.

CHAPTER FOURTEEN

What's Still Open

Not everything here earned its place by the same route. Some was tested against events. Some has not happened yet

A book built this way owes the reader a clear line between what has been checked and what has only been reasoned through. Most of what came before belongs on the first side. A few things belong on the second, and they should be named rather than left to blend in with everything confirmed.

The Fee Mechanism Is Sound. It Has Not Been Sustained.

Part Three's central claim, that a fee lowers the energy behind each coin a miner ends up holding and gets partly competed away as hashrate arrives, follows from mechanisms tested elsewhere in the book. The joule limit, one machine's efficiency, is not what any of it touches. The reasoning holds. What has not arrived, at least not for any sustained stretch, is a fee spike large enough to test the claim at scale. Every network drawn on here has kept fees small against issuance for its entire history. The mechanism is sound. It also remains, honestly, mostly theoretical.

> *A sound mechanism and an observed one are not the same claim. This book has offered the first. It cannot yet offer the second.*

How Fees Redistribute Is Still an Open Question

This book showed fees lowering the energy behind each coin a miner ends up holding, and being competed away over time as any profitability gap is. It never worked out the deeper question of how sustained fee revenue should be distributed once large enough to matter, whether some share should smooth across time instead of paying out block by block, and what that would do to income stability for miners. An open design question, not a settled one, and the book leaves it where it found it.

A Structural Claim, Not Yet a Historical One

One boundary deserves stating outright, and it sits on the downward half of the mechanism. The joule limit steps down only while somebody is willing to pay for the next machine to exist. That willingness is not guaranteed and not scheduled. It depends on a return that a long, flat market can erase entirely, and when it does, the ratchet holds rather than advances. Nothing already gained comes back, so the direction survives, but a stalled limit also means the two movements stop offsetting each other, and the cost of a coin climbs faster while it lasts. Whether the physical ceiling or the economic one binds harder over the coming decades is a live question this book does not answer.

A second open question is larger still: whether the handover completes, which is arithmetic meeting a deadline. Issuance falls on a schedule nobody can amend. Fee revenue rises only as fast as a network gets used. Nothing guarantees the second overtakes the first before the first reaches nothing, and no amount of reasoning settles whether it will. The bar exists. Nothing here proves it unclearable.

There is a counterargument the mechanism itself supplies, and it deserves stating even though nothing has tested it. The question is usually asked in coins: can fee revenue reach the number of coins issuance used to pay? That may be the wrong denominator. What buys mining is not a count of coins but what those coins command, and the same thinning of issuance that shrinks the count also thins the supply available to buyers. Against persistent demand, fewer coins offered means each one commands more.

If that holds, the budget can clear at a far smaller number of fee-coins than a coin-for-coin replacement implies. The familiar framing, of fees

needing to reach some percentage of the whole stock, then asks about a quantity the mechanism has no reason to care about. The question worth asking is what a marginal fee buys in real work, not what fraction of the coins it represents.

Stated at full strength it would be an equilibrium claim about a state nobody has observed, which is why it sits here rather than in the fee chapter. It also depends on the same demand floor named below. Thinning supply raises price only where someone is still bidding.

Two Conditions the Upward Claim Rests On

The argument that a coin gets harder to make over time carries two assumptions, and both deserve stating rather than absorbing.

The first is that a floor of demand persists. Some quantity of buyers who do not leave, whatever the price does, for whatever reason. Above some level of adoption that seems safe to assume, and below it the whole argument dissolves, because supply thinning against nothing is not a gap. Where that level sits, and whether a given network has cleared it, is not something this book can measure.

The second is a race whose outcome is only known so far. Each gap is smaller than the last, so the upward steps shrink. Efficiency gains are also shrinking, bounded by physics at one end and by whether anybody funds the next generation at the other. Both quantities are diminishing, and which diminishes faster decides whether the cost of producing a coin keeps climbing or eventually turns over.

Nothing observed so far suggests the turn has happened. That is not the same as showing it cannot, and the honest position is that the direction has held for as long as anyone has been able to watch, over a span short enough that a reasonable person could call it early.

Why This Matters More Than It Might Seem To

What came before survives all of it. A mechanism reasoned correctly from tested pieces has value before the event it describes occurs. The alternative, waiting until every claim has been observed at scale before writing any of it down, means writing only about things that already finished happening.

What matters is refusing to blur the difference. Anyone finishing this book should know which claims rest on events that occurred and which rest on reasoning events have not yet touched. Both have value. Only one deserves to be called settled.

Closing

This book opened before price existed, when machines were running and nothing was pricing them, and closed by testing its name against everything built between. The name held. The mechanism it names, fast and reversible up close, slow and one-way from a distance, is the whole of what it set out to show.

What remains unsettled is named plainly, not as a weakness, but as the honest edge of what has been checked.